VOLUME 83 NO. HW3
JULY 1957

JOURNAL of the

Highway Division

PROCEEDINGS OF THE

AMERICAN SOCIETY OF CIVIL ENGINEERS

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8. Papers should average about 12,000 words in length and should be no longer than 18,000 words. As an approximation, each full page of typed text, table, or illustration is the equivalent of 300 words.

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AT,BD,CP,CO,HW,IR,SU,WW,PL.

Journal of the

HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

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LOCATION NEEDS TO GET FULL BENEFITS FROM FREEWAYS

R. N. Grunow,[1] M. ASCE
(Proc. Paper 1294)

ABSTRACT

Freeways should be located to best serve traffic demands. General locations can be determined by the techniques of Origin-Destination Studies. Specific locations are influenced by topography, right-of-way, and construction costs. Where two or more routes are feasible within a general location, determination of the final line should be made upon the results of a road user benefit analysis.

There are several thousand miles of rural freeways and a few hundred miles of urban freeways in existance today. Only a few miles exist in the southeast. 40,000 miles of freeways will be built in the next thirteen years as directed by Congress in the 1956 Federal-aid Highway Act. Some of the existing mileage will be incorporated into the 40,000 mile system—other will not. 6,700 miles of the 40,000 will be in urban areas. Additional mileage will be built, as justified, to supplement the Interstate System.

The only reason to build roads and streets is to efficiently serve the traffic demands. Wherever conventional roads and streets cannot safely and efficiently serve traffic demands between centers of heavy traffic generation, freeways should be located and built to meet these demands. Under favorable conditions the conventional city street can carry approximately 600 vehicles per lane per hour. One lane of a freeway can carry at least 1500 vehicles per lane per hour and do it more safely.

Freeways are specified for the Interstate system which has been defined between major areas of traffic generation or control areas. This system is now in the process of being located. The task of the highway engineer in locating the system in, through, around and between the traffic generators is not easy and he is confronted with many complex problems.

Note: Discussion open until December 1, 1957. Paper 1294 is part of the copyrighted Journal of the Highways Division of the American Society of Civil Engineers, Vol. 83, No. HW 3, July, 1957.

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The principal problem is to locate a freeway so as to provide the most efficient service to the traffic that will use it. There is available a technique to aid in the selection of a location with respect to traffic service, a technique known as Origin-Destination Studies. Information as to vehicle trips is obtained simply by stopping the vehicle and asking the driver where the particular trip started and where it will end. The interviewed trips are then related to total trips, usually obtained by automatic traffic counters. The result is an evaluation as to magnitude and direction of all vehicular trips in the geographical area under study. A projection of past vehicular traffic into the future will permit an estimate as to the probable assignable traffic to a given location at a specified future date, or the design year.

This technique is not new, it has been used on hundreds of occasions and is time tested. Variations have been introduced to supply answers to specific problems. Although the basic principle has been unchanged, it is not static. Research is continually in progress to make improvements. One promising study in this field is the relationship of land use and traffic generation. As more freeways are placed in operation additional studies of vehicle travel gravitating to and operating upon them can be made with the result that techniques can be perfected and more accurate predictions of future assignable traffic can be developed.

O-D Studies can be made for any geographical size area, an entire State or a portion thereof, a county or city. The most frequent use has been for urban areas. There are four principal types of O-D Studies used in urban areas depending upon the population size and problems encountered: These are:

1) External Cordon
2) External Cordon—Internal Cordon
3) External Cordon—Parking
4) External Cordon—Home Interview

All four types embrace roadside interview of traffic at the external cordon—an imaginary line intercepting all roads entering the urban area at the outer extremities of the urban development. Reference to the schematic diagram in Chart 1 shows the several classification groups of trips and the extent to which information for each class can be developed from the four types of O-D studies. For the simple external cordon study, interviews would usually furnish information on five of nine classifications; (1) External—External, (2) External—Internal, for trips not through the Central Business District; and (3) External—External, (4) External—Internal for trips through the CBD, and (5) External-CBD. No information would be available regarding trips originating and ending inside the cordon line: Classifications 6, 7, 8, and 9. The simple external cordon type of study is recommended for only the smaller places under 5,000 population.

Type 2 embraces in addition to the external interviews, interviews at an inner cordon. This is an imaginary line intercepting all streets entering the Central Business District (CBD) or core of the urban area. Trips interviewed in addition to (1), (2), (3), (4) and (5) are (6) Internal-Internal passing through the CBD, and (7) Internal—CBD. This type of survey is recommended for places with a population from 5,000 to 50,000 where most of the traffic is to the downtown district or is through traffic and there are no major deficiencies in the existing street system outside the downtown area.

The External Cordon—Parking (Type 3) is an external survey with a

parking study in the CBD. Its use is also recommended for urban places from 5,000 to 50,000 population where there are major parking problems in the CBD and there are but few traffic problems outside this area. The classes of trips intercepted by interview in this type of study includes all except (6) and (9). The above studies include only motor-vehicle trips.

The External Cordon-Home Interview survey samples information on all trips irrespective of mode of transportation. Persons are interviewed in their homes regarding the trips they made on the previous weekday and the mode of transportation used. This type survey permits all the trips within the urban area to be assembled and evaluated. Sampling techniques are employed based on the number of dwelling units. The recommended size of the sample varies from 20 percent for places under 50,000 to 4 percent for places over 1,000,000 population. It is generally recommended for use in places over 50,000 population but can be used in any size city where major traffic problems exist throughout, or where transit rider problems and major vehicular traffic routing problems are important.

A variation of the home interview method has been employed with questionable results. This is known as the controlled postcard survey. A returnable postcard is mailed to all owners of vehicles registered in the study area. They are asked to list their preceding weekday travel by individual trips. Through this method it was hoped to reduce the cost of employing personnel necessary to make the home interviews and the cost of their supervision. Experience here lends proof to the old adage that "economy is not always the best policy." While the size of the sample is larger than for the home interview, the information as to trip purpose, time of trip and mode of travel are lacking. Certain "biases" are also inherent because good returns may be made by people from one strata of community life and poor returns from others. The controlled post card method is not recommended as a substitute for the home interview.

A simple but effective summary of average trip destinations has been published by the U.S. Bureau of Public Roads from information obtained from thousands of external studies. It is referred to as Chart 2. The percentage of total trips through the external cordon classified by Types 1, 2, 3, 4, and 5 according to Chart 2 are summarized by population groups. Some 52 percent of all traffic approaching cities under 5,000 population does not desire to go to these places. This percentage decreases as the size the place increases. For cities of 500,000 to 1,000,000 it is only 7 percent. Certainly freeways would not be located through places under 5,000 population, and may not be justified through cities up to 25,000, to which 35 percent of the approach traffic is by-passable. Chart 2 represents percentage and not volume of approach traffic. Freeways are justified for large volumes. The locations of freeways, such as the interstate system, would and should provide service to as many isolated communities as possible when these cities are located along the projection of a route between control areas and their accumulated traffic generation so warrants. This is in accord with the spirit of the 1956 Federal-aid Highway Act for this system. The system is not intended to serve all traffic. Service to communities not directly served by the Interstate system is provided for through regular urban, primary and secondary road improvement programs. Substantial increases to aid the states for improving these systems has been provided for in the 1956 Act.

A few examples will show how information from O-D Studies helped find proper solutions to specific problems.

A proposed location of the interstate system in the vicinity of Laurel, Mississippi (population 25,035) was advanced to the east and separated from the city by a river. An O-D survey here showed 75 percent of the traffic approaching the city was destined for Laurel with the heavier movement to the south toward Hattiesburg. As a result of the O-D facts the system was finally located into the city near the C.B.D. to serve the large traffic destined to this area.

Jackson, Tennessee with a population of 30,207 is about the same size place as Laurel, Mississippi. 25 percent of the external traffic was found to be through traffic and 75 percent was destined for the urban area. In this case the interstate system has been located outside the corporate limits where service to the urban area will be provided by improved connecting arterials.

Chart 2 also shows that as the population increases above 10,000, the percent of traffic destined for the C.B.D. decreases and that destined for other parts of the city increases.

For the larger percentage of traffic destined for cities over 5,000 population, the magnitude and direction of this traffic within the city should be measured and evaluated.

The combination of external and internal movements usually tells the story in terms of trips per day. The direction of these movements can be so widespread that no single route is indicated, and a complex urban system may be required to answer traffic needs.

The C.B.D. is usually the big generator. It is relatively small in areas with a heavy vehicular trip movement. Even though the percent of external trips to this area decreases as the population size increases, the volume of trips from this movement alone might determine freeway location. This was one of the considerations for locating the Atlanta, Georgia, freeway system into the C.B.D. from all four cardinal directions. It was further justified when a considerable number of internal trips could be accommodated along the same location. The magnitude and direction of trips to the northwest and northeast in Atlanta dictated that freeways should be provided in both these directions. Other interval movements coupled with the interchange of traffic to major highways radiating from Atlanta and projected to the design year substantiated the need for a 360 degree circumferential route. This is now being planned.

Trip movement through the central business district (3), (4) and particularly (6) (see Chart 1) can be large and cause undue congestion in the C.B.D. In Memphis, Tennessee where one of the first O-D home interview studies in the country was made, these movements were found to be 56 percent of all the traffic in the C.B.D. As a result a freeway is now being planned to serve this traffic which will take it out of this area and free the streets for the traffic destined to it. Similar conditions have been found to exist in other urban areas.

In the Jacksonville, Florida, O-D Study a large movement of vehicles from the southwestern part of the city to the ocean beaches on the east was discovered and defined. It was not previously known to exist in the magnitude brought out by the survey. Due to the location of the two existing bridges across the St. Johns river, this traffic was absorbed in that to and from the C.B.D. This O-D Study pointed up the need for a third river crossing located so as to take this movement out of the downtown area. This third river crossing which has been built would serve this one local traffic demand and

also the location of the interstate system for the north-south route. Provision is also made for an adequate connection with the route west from Jacksonville.

Data from these surveys are usually summarized by total desire trip movements between the pre-selected zones. The summary is shown pictorially in the form of desire-line movements as on Chart 3. Further interpretation is needed to eliminate all minor movements and consolidate the major directional movements as illustrated on Chart 4. It is not intended to say here that this information is all that is needed to locate a freeway or system of freeways. It does define in general terms the magnitude and direction of vehicle movements if facilities were available for these movements in the particular area. It does give the Location Engineer the general area such as north, south, east or west of the C.B.D. in which to locate a facility. It does fix the limits within an area several blocks wide. If located within the general area, the traffic information will be sufficient to determine the number of lanes needed, and the number, general location and type of interchanges. It may not fix the exact location. This is only done after extensive field and office studies, and concluded when the right-of-way has been made available and construction begins.

Armed with factual information as to traffic desires and needs, the Locating Engineer then seeks out feasible locations in the general area as dictated by topography and right-of-way considerations. He considers families displaced, business moved, utility to be adjusted, and many other factors.

Often consideration of alternate locations of a route or a section of a route involving similar traffic, terrain, and design characteristics is necessary due to topography and right-of-way obstacles. A method has been developed making simple and practical analyses of these situations, based on benefits to road users. Here O-D information is essential. The road user benefit analysis is simply a comparison of total annual road user costs and total annual highway costs of one route with another. When all components are considered, a route with higher initial construction cost is often the more economical. Proper location for efficient service to the most traffic will return high annual savings to motorists.

Certainly the results of O-D studies should be used for general locations to determine their magnitude and direction.

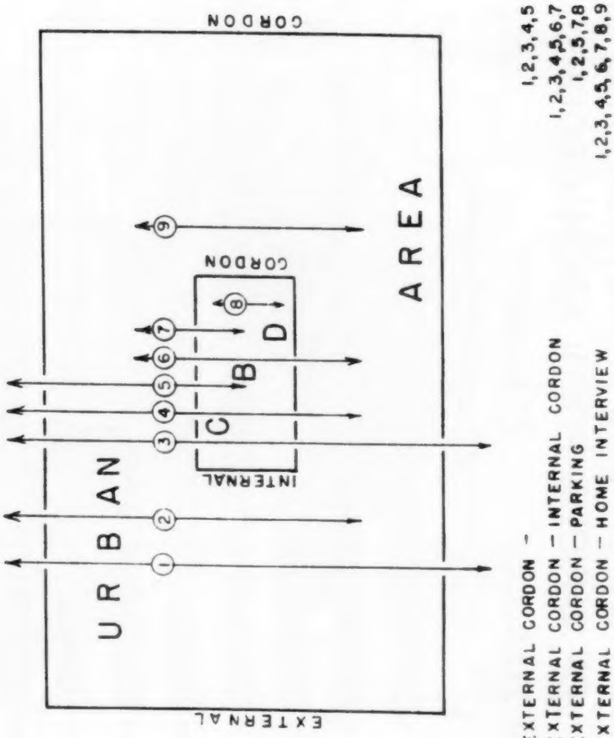
Freeways, even more certainly than other roads and streets, are located, designed, and built not only to serve present needs but future needs. O-D studies have to be projected into the future, utilizing the best possible estimates as to future land use, population increases and distribution, motor vehicle use and other transportation trends and increases. Such far reaching highway planning operations not only require consultation with, but the strongest support of local planner and community interests. The transportation services that will follow the development of a system of freeways such as the Interstate System will have a tremendous effect on all urban places. Where alert planning authorities exist, freeway developments are dovetailed into their future plans. Where planning authorities do not exist, the freeway system will dictate to a large extent the future development of the area.

Specific locations are influenced by topography, right-of-way and construction costs. The choice of alternate specific locations should be reached only after a road user benefit analysis of each alternate has been made.

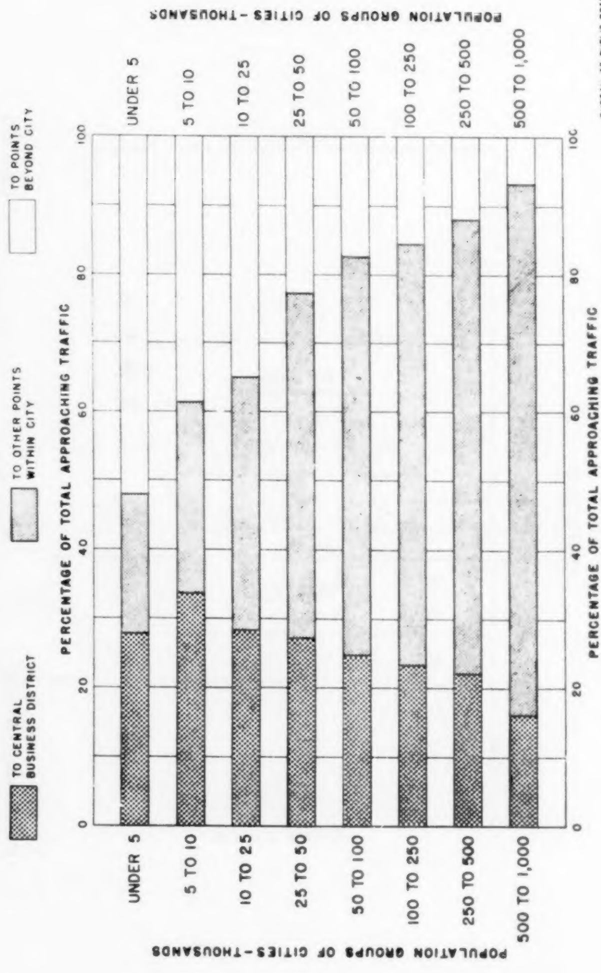
There is no easy rule to freeway location. Intensive study of the need for traffic services, topography, costs of right-of-way and construction and effects on the present and future developments of the area is necessary if the location requirements to obtain full benefits from Freeways are to be consummated.

SCHEMATIC DIAGRAM OF VEHICLE TRIPS IN AND THRU AN URBAN AREA

CHART I

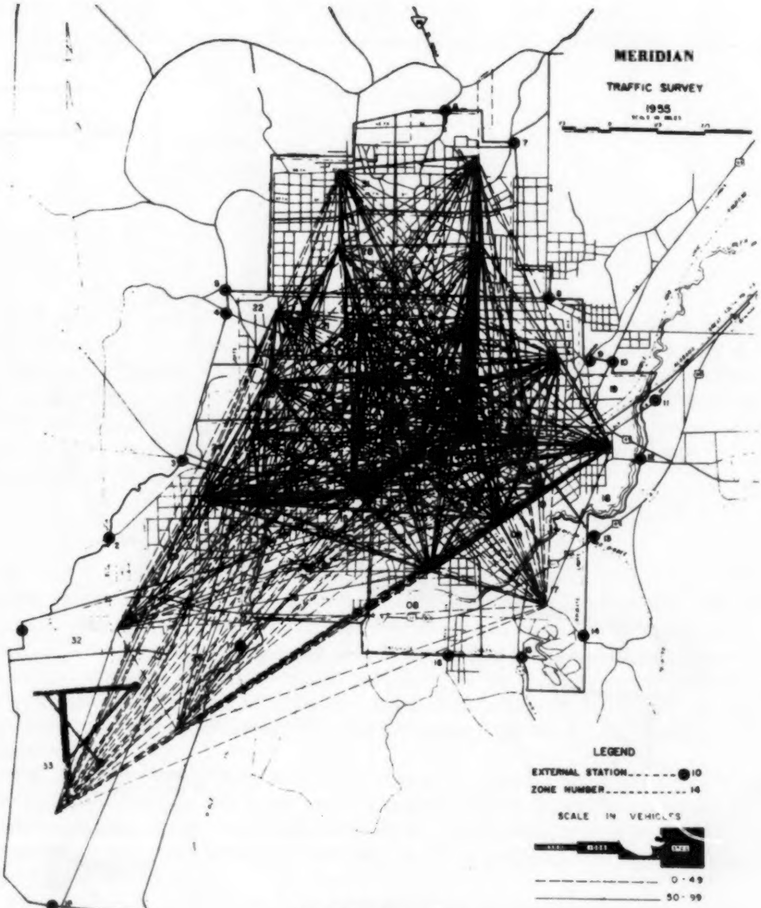


DESTINATION OF TRAFFIC APPROACHING CITIES OF VARIOUS POPULATION GROUPS



BUREAU OF PUBLIC ROADS
DEPARTMENT OF COMMERCE
JUNE 1952 T-16

CHART 2



MERIDIAN
TRAFFIC SURVEY
1955
LEGEND
EXTERNAL STATION
ZONE NUMBER
SCALE IN VEHICLES
0 - 49
50 - 99

CHART 3

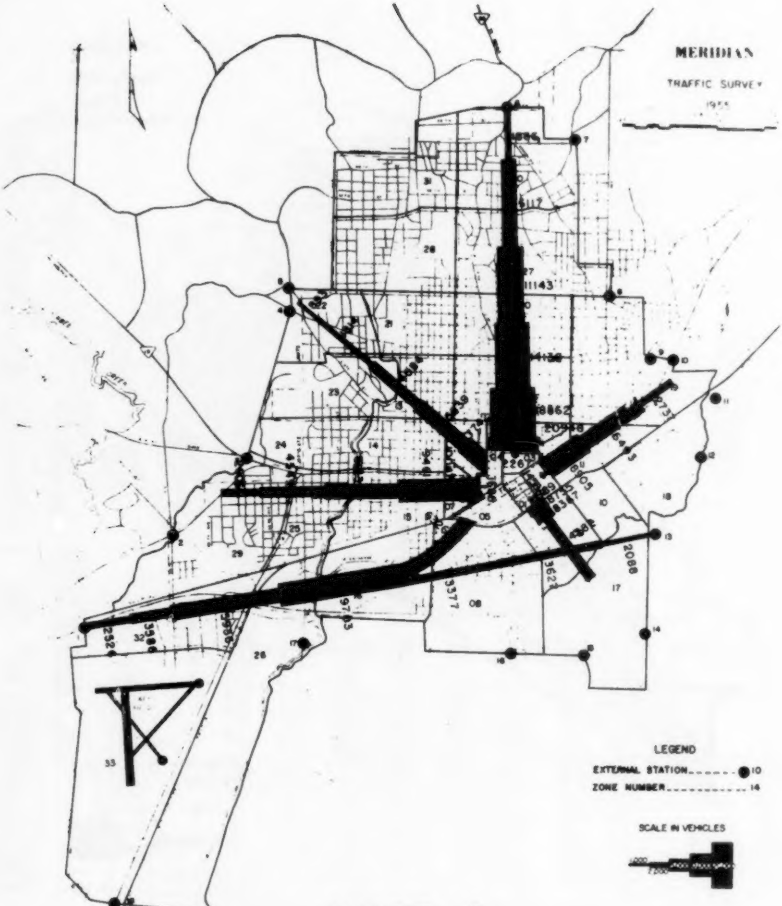

MERIDIAN
TRAFFIC SURVEY
LEGEND
EXTERNAL STATION
ZONE NUMBER
SCALE IN VEHICLES

CHART 4

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

FREEWAY BENEFITS

Terry J. Owens,[1] M. ASCE
(Proc. Paper 1295)

ABSTRACT

From every angle of measurement, freeways have benefits which justify their construction. Fatality rates are only half and accident rates only a fifth of those on important surface arteries. Time savings generally are substantial on freeways, and so are dollar savings. Studies indicate many freeways pay for themselves in just a few years, others in from 10 to 20 years. Freeways not only increase property values but stimulate residential and industrial development.

In recent years the freeway and its blood brother the toll road have been making their influence felt in the continuous evolution of the nation. As surely as the waterways of the 1700's and the railroads of the 1800's left their trace on the nation's development, the freeways of today are shaping the economic and cultural patterns for tomorrow. The 84th Congress in passing the Federal-aid Highway Act of 1956 has made it possible to construct the 41,000-mile National System of Interstate and Defense Highways to freeway standards.

The term "freeway" has no connection with whether the highway is a toll or free facility. Rather, the term refers to freedom of movement without traffic signals. All crossings are separated by bridges, pedestrians are excluded and abutting property is denied access. Access and exit are by carefully designed ramps only.

Freeways now in service have unmistakably demonstrated their value. Numerous well documented studies have been made on freeway operations and their effect on surrounding areas. Analysis of these studies reveals that the same type of benefits occur in both rural and urban areas but not in the same degree. Generally benefits are more pronounced in urban areas.

In reviewing some of the specific benefits, let us first consider safety. In

Note: Discussion open until December 1, 1957. Paper 1295 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 83, No. HW 3, July, 1957.

1. Urban Highway Engr., Automotive Safety Foundation, Washington, D. C.

urban areas records show that freeways have only half the fatalities and one-fifth the total accidents of important surface arteries.

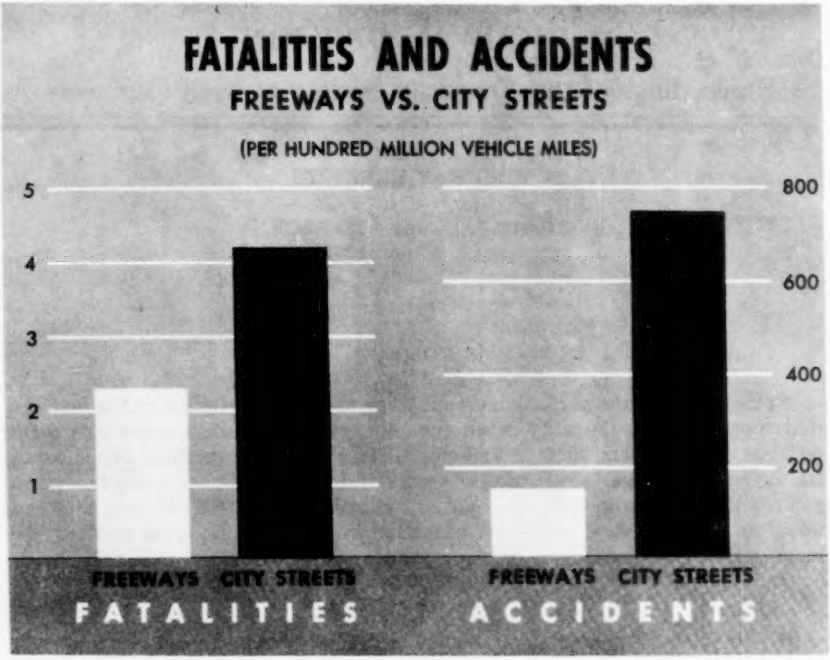


Fig. 1. FATALITIES AND ACCIDENTS

On the other hand it should be stressed that motorists must learn to drive these new highways. Accident rates the first year of operation of new freeways are nearly always higher than those of succeeding years. This is because the driver must master new techniques for freeway driving, also because he has to become thoroughly familiar with his daily route, thus building confidence to replace uncertainty. Although the first year's rates are higher, nevertheless they compare favorably as a rule with those of surface arterial rates.

A second significant benefit of freeways is time saving. Because of freedom from cross traffic and friction from abutting property, the freeway driver keeps his vehicle in motion at a fairly uniform rate of speed. His principal concern is the vehicles leaving or entering the freeway at ramps intended for that purpose. Ramps are designed to accomplish these movements with a minimum of turbulence to the freeway lanes. However, it is found that the lanes next to the ramps carry less traffic and move slower than other lanes.

In rural areas the success of toll roads clearly demonstrates the desire of users to save time, even though a premium fee is required. Observations show, in fact, that the ratio of traffic using a toll road bears a close relationship to ratio of time saved on that road as against the conventional route.

Because of variations in speed limits, topography, truck traffic and congestion, it is inadvisable to make comparisons of rural freeway time savings except for specific routes. It has been found that under normal conditions the following trip times may be expected:

Actual Trip Time	Via Highway	Via Freeway	Time Saved	Percent Time Saved
Washington, D.C.-New York*	7:10	5:35	1:35	22
New York City-Buffalo	11:00	7:00	4:00	36
Pittsburgh-Philadelphia	7:20	5:15	2:05	28
Houston-Galveston	1:15	1:00	0:15	20
Tulsa-Oklahoma City	2:40	2:15	0:25	16
Pittsburgh-Chicago	11:05	7:20	3:55	36

*Not built to full freeway standards for entire distance.

In addition, the following time savings have been estimated for some proposed interstate routes.

	Trip Time	Estimated @ 55 mph	Time Saved	Percent Time Saved
New York-Miami	34:15	24:00	10:15	30
New York-Los Angeles	67:00	50:00	17:00	25
Boston-Albany	4:20	3:15	1:15	29
Cheyenne-Salt Lake City	9:30	8:35	1:00	11
Portland-Sacramento	17:10	11:20	5:84	34

In some urban areas studies have been made to compare freeway travel time with that of surface arterials.

Findings in Los Angeles indicated that freeway speeds averaged 48 mph between points, while arterial speeds averaged 20 mph.

Houston found that the Gulf Freeway saves 2 1/2 minutes per mile of travel.

The six-mile Congress Street Expressway in Chicago requires eight minutes to traverse, as against 25 to 40 minutes on conventional streets.

In Seattle motorists using the present length of the Alaskan Way save eight minutes.

From these random samples it can be seen that the time savings of highways with full control of access are substantial. It is especially this feature of freeways that has made them so popular with motorists.

Freeways also have an important impact on property values. In general it can be said that freeways enhance the value of all property close enough to

benefit from its superior transportation service. It is also true that values of unimproved land increase more percentage-wise than does developed property. This does not mean that a few properties here and there have not lost value because of the freeway. But these cases are relatively rare and may be disregarded from the standpoint of establishing broad policy. Even where they occur, the decrease represents only a small fraction of the market value of the property.

In the suburban areas of a large metropolis, freeways make it possible for workers to live in the country and work in the city. This has stimulated large subdivision development in many places.

Case histories in Boston, Los Angeles, Houston, Oakland and Kansas City reveal that potential industrial sites skyrocket in value when served by a freeway.

Of considerable concern to vehicle operators is the question, "How do freeways affect vehicle operating costs?" In rural areas operating cost savings generally are not as great as in urban areas, because in rural areas stop lights are infrequent and vehicles tend to maintain a fairly uniform pace. However, variations in both directions are evidenced by case studies. A trucking company operating over the New York Thruway showed appreciable savings in fuel, time, and maintenance for the freeway as against ordinary roads. Conversely, the operating cost for passenger cars traveling 60 mph will be more than for 45-50 mph on a conventional highway reasonably free of stops and congestion.

It is in urban areas that freeways consistently show reduced operating costs. The previously mentioned Los Angeles study found that freeway users saved 1.13 cents per mile, computed as follows:

Gasoline Savings	0.33 cents
Vehicle maintenance due to elimination of stop and go	0.24 cents
Accident Savings	0.56 cents
	1.13 cents

These savings have been verified by other studies developed from different source material.[1]

The value of time savings affects three groups of motorists. Economists are not agreed on the validity of time savings for all groups.

First is the value of time savings to commercial vehicles which all economists agree is valid. When these savings are computed and prorated to all vehicles it brings the average savings to all vehicles to two cents per mile.

Second, and equally valid, is the value of time savings to businessmen, doctors, salesmen and similar persons utilizing the freeways in performing their daily work. Although valid, this group is impossible to identify in the traffic stream and the savings are therefore not measurable.

The third group is the remainder of the traffic stream comprised of people going to and from work, or on social or recreational trips. Some economists reason that the value of time savings for this group is not valid because their time has no value. This position is debatable as people using toll roads prove that they place a monetary value on their time.

1. Economy of Freeways, City of Los Angeles
A Study of Freeway System Benefits - City of Los Angeles

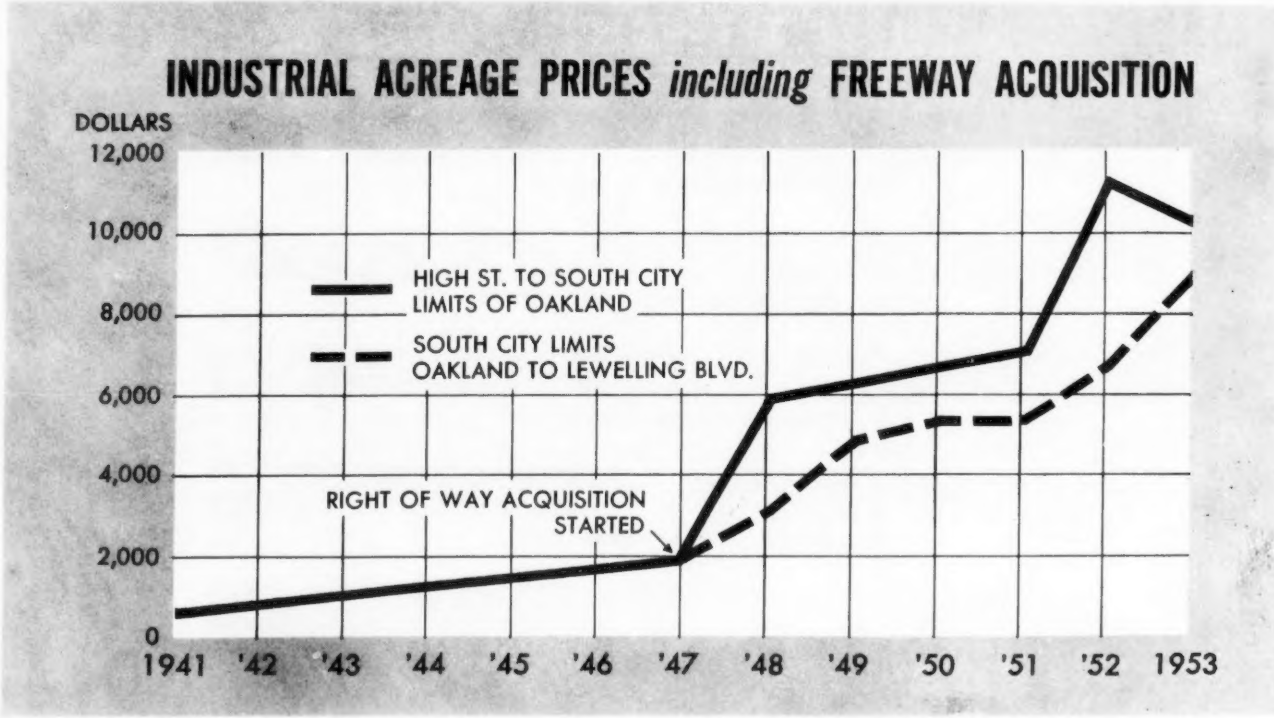


Fig. 2. INDUSTRIAL ACREAGE PRICES including FREEWAY ACQUISITION.

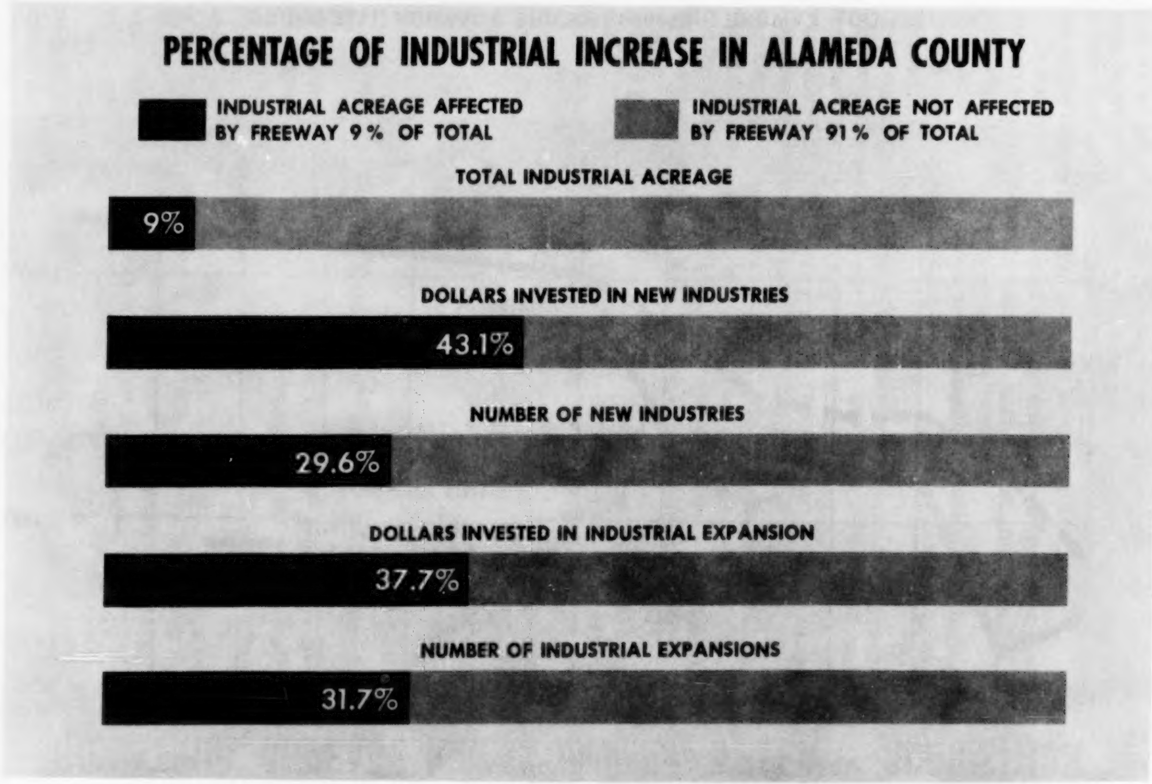


Fig. 3. PERCENTAGE OF INDUSTRIAL INCREASE IN ALAMEDA COUNTY.

If it is accepted that a monetary equivalent for time saving is valid for all vehicles (as demonstrated by toll road success), the total savings for the average vehicle is 4.16 cents per vehicle mile.

When operating savings such as these are applied to heavy-volume urban freeways, the savings repay the original cost in comparatively few years. For example, if the two cents per mile is applied to various freeways the cost would be reimbursed in the following time periods:

Los Angeles 46.3 miles of freeway	8 years
San Diego Cabrillo Freeway	4 years
Detroit	20 years
Atlanta	8 years
Cleveland	11 years
Houston	5 years
Dallas	10 years

Since the pavements (which account for from 5 to 25 percent of the total cost) should last for 25 years, these freeways clearly are good investments. Moreover, though the pavements may require replacement after a quarter of a century, the structures should be good for 50 years. The right of way, grading and other improvements will have a useful life and salvage value well beyond that period.

No discussion of freeway benefits can ignore the subject of traffic volumes. Capacity to handle extraordinary traffic volumes safely and efficiently is a prime feature of freeway design.

Planners have considered that 1,500 vehicles per lane per hour is acceptable for design purposes. Recent investigations have proven this figure to be generally sound. Increases in the percentage of truck traffic and ascending grades of as little as two percent adversely affect lane capacities. Occasionally lane volumes considerably exceed the 1500 vph rate.

The studies conducted by the California Division of Highways show that there is considerable variation in the volumes carried by different lanes of a freeway. There, observations have led to the conclusion that for comfortable operations the outside lane adjoining the ramps will carry 800 vph, the next lane 1,100, while the third and fourth will each carry 1,800. This is a total of 5,500 for four lanes, whereas the 1,500 per lane would produce 6,000 vph. Volumes in excess of these for sustained periods would probably result in reduced speed and some congestion.

The best average lane volumes on arterial streets approximate only 600 vph. On the basis of 1,500 vph per lane for freeways and using the Highway Capacity Manual for arterial streets, it is calculated that one freeway with three lanes in each direction can carry as much traffic as three two-way arterial streets 60 feet wide with all parking removed.

At the same time the average speed is more than twice as fast on the freeway and the chances for an accident only one-fifth as great.

In addition to the high volumes carried by freeways, they afford substantial relief to congested parallel arterial streets. Counts before and after freeway openings show volume reductions of from 30 to 50 percent on nearby arterial streets. These reductions tend to increase average speed as much as 25 percent. This means that the freeway raises the standards of transportation with respect both to freeway itself and other streets as well.

Proprietors of commercial establishments have often resisted freeway construction on the grounds that the freeway would take their customers away.

Numerous studies have shown that the opposite is true. When the traffic congestion in front of their doors is relieved their customers can reach them more easily. Numerous case studies prove that in this situation business gains on these relieved routes exceed the gains of the area as a whole. For example, the following chart shows the relation between business on the old highway and business county-wide in Sacramento County, California, after the construction of a new freeway.

It would be to the advantage of cities to give more attention to providing transit loading facilities on proposed freeways. A number of transit organizations now using urban freeways have markedly benefited. Patronage is increasing due to the substantial time savings. Chicago is going a step further by providing for rail transit in the median strip. Growing congestion in most cities dictates that the transportation facilities be operated at the top level of efficiency. Buses adequately powered for freeway operation can do much to speed the movement of people to and from the business district. However, it is essential that suitable loading areas be provided away from the through lanes.

Many communities across the nation are plagued with neighborhood decay. Some cities are actively engaged in clearing and rebuilding these areas and many more must undertake this work in the near future. The rebuilding may take the form of high density housing, industrial or commercial redevelopment. Regardless of the type of redevelopment, the transportation needs of the area are increased. This means that the highway network must be revamped to accommodate the increased demand. A number of cities have integrated their redevelopment plans with highway needs. The resulting product produces economy in land acquisition and more effective transportation service.

Too frequently, long range urban highway needs are based on present use plus estimated growth, without vital supporting data on future land use, density zoning, school and recreational location and similar factors related to traffic generation. It has been found that highways, particularly freeways, are effective buffer strips between residential, industrial, or commercial zoned areas.

To sum up the benefits of freeways over conventional roads or streets:

1. Freeways usually average only one-half the fatal accident rate and one-fifth the total accident rate of other main highways.

2. Time savings to users average 30 percent in rural areas and upwards of 50 percent in urban areas.

3. Direct vehicle operating cost savings are considerable on freeways.

4. When the values of operating time and accident savings are combined, the savings quickly repay the initial cost of the freeway.

5. Freeways increase property values in areas influenced by the facility.

6. Freeways stimulate residential and industrial development.

7. Freeways stimulate business on streets relieved of congestion.

8. Freeways assist in the orderly and planned development of urban areas.

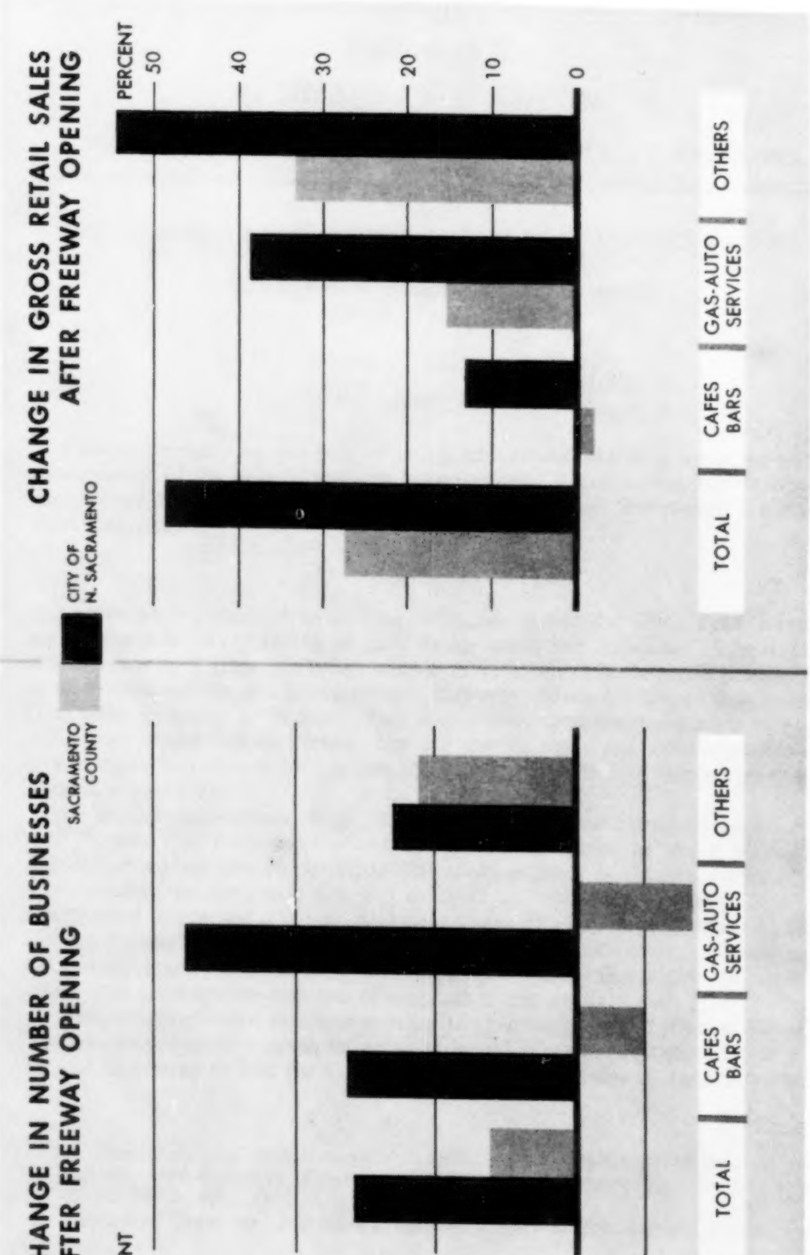


Fig. 4. CHANGE IN NUMBER OF BUSINESSES AFTER FREEWAY OPENING.

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

THE PLANNING ROLE IN PITTSBURGH'S PENN-LINCOLN PARKWAY

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(Proc. Paper 1296)

ABSTRACT

This paper outlines the role of city planners and planning agencies in the development of the new Pittsburgh Renaissance. It describes in detail the background and planning of the Penn-Lincoln Parkway, Pittsburgh's East-West Expressway.

One basis of judgment in this world is that of comparison. This is true for students of city planning as well as for any other endeavor. The first-time visitor to Pittsburgh today sees a bustling city spotted with evidences of new construction and development, and many other evidences that much, obviously, remains to be done. Our new visitor may compare what he sees with other cities that he knows. But the one startling and most significant comparison he lacks is that of today's Pittsburgh with the Pittsburgh of a mere ten years ago.

In order to appreciate, fully, the great changes that have taken place in the past decade, one must know what the city was like prior to World War II. This giant among industrial cities was choking itself in its own smog. Periodically, floods would overrun many of the low-lying industrial and residential areas and a substantial part of the city's business district, the Golden Triangle. The city rapidly was becoming obsolescent, and nothing was being done to rebuild or build anew, either in public or private construction. The atmosphere was one of stagnation and decay.

Now, slightly more than ten years after the beginning of its new effort, Pittsburgh presents a much brighter face and gives every indication that it is just beginning to flex its muscles in its drive to make of itself a better city.

Note: Discussion open until December 1, 1957. Paper 1296 is part of the copyrighted Journal of the Highways Division of the American Society of Civil Engineers, Vol. 83, No. HW 3, July, 1957.

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The story of this regeneration has been told in print a number of times and may be familiar to many who read this. But the manner in which it was brought about should provide a basic guide for other cities in attacking their problems, and, for this purpose, the story bears repeating.

A City's Rebirth

The story of the new Pittsburgh begins in 1943 with the formation of The Allegheny Conference on Community Development. Official and citizens' planning groups had, in earlier years, done much of the planning groundwork that was to serve as a basis for projects to come. But it was the Allegheny Conference that collected and evaluated the plans that had been made, conducted substantial research on its own, and, after developing a program, marshalled all of the local forces behind it to spark the most major face-lifting of any city in the country.

The Conference is a civic agency composed of top men in the community—leaders of business and industry and key public officials. Supplemented by a small but experienced professional staff, these men give their own time to study and discuss possible courses of action; then, upon deciding, use all of the forces at their command—and these are considerable—to bring about that action.

In these years the City, County and State administrations have worked diligently to bring about the many improvements that have resulted. Where the Pittsburgh Program is concerned, partisan politics have been set aside and all levels of government, whether Democratic or Republican, have worked together harmoniously to achieve the common goal. In fact, as a few ambitious office-seekers have learned to their sorrow, the adoption of a platform opposing some phase of Pittsburgh's redevelopment is a certain guarantee of defeat.

In the first few years of its existence, the Conference directed its attention, primarily, to research and study. Reports were prepared on such subjects as Smoke Control, Flood Control, Sanitation, Industry, Parks and Recreation, Highways and Parking. After the close of World War II it supported actively the two elements of the program which were basic to most of the remainder—smoke control and flood control. Also, it gave its full support to the Penn-Lincoln Parkway, described in greater detail later.

Then in 1947 the Allegheny Conference, local public officials and political leaders pushed through the state legislature the most complete program of legislation ever to deal with one city, a group of eight bills which came to be known as the "Pittsburgh Package." These laws dealt with smoke control, housing, subdivision control, refuse, recreation, mass transportation, off-street parking and highways.

Spurred by the enacting of the new legislation and the already apparent effects of the smoke control and flood control programs, civic planners and public officials alike advanced the effort on many fronts during the next few years. Concrete evidences of an improving city created a desire for greater improvements, and the realization dawned that diverse elements really could work together in this drive to create a better city.

The smoke control program, so successful in the City, was enlarged to include the metropolitan area of the County. Of all the elements of the program, smoke control hit closest to the grass-roots of the community. Every home,

business, and industry was required to burn smokeless fuels and adhere to other provisions of the law. An overwhelming majority of the people are so delighted with the cleaner air that very few would ever consider going back to the old days of black dirt settling over the city and depressing everything it touched. In 1946 there were 298 hours of heavy smoke compared with 10 hours in 1955. And in the past ten years there has been a reduction of 89% in total smoke.

With the continuing of the Federal program of flood control in the upper Ohio River Valley, the threat of a major flood to Pittsburgh no longer exists. Eight impounding reservoirs located on the tributaries of the Allegheny and Monongahela rivers will take approximately ten feet off the flood crest of any predictable river stage at the point of the Triangle. Three other dams in the planning stages will reduce the crest even more.

In addition to the Penn-Lincoln Parkway, the metropolitan area's longest and heaviest volume freeway, several other highway projects are either in construction or in planning stages. A five-mile extension of McKnight Road, completed about a year ago, provides a convenient connection to Route 19 in the north. The Etna-Sharpsburg By-pass, now under construction, is a seven-mile limited access expressway on the north side of the Allegheny River, which will carry traffic through three extremely congested municipalities. In addition, the Crosstown Boulevard on the eastern edge of the Triangle and the extension of the Ohio River Boulevard to the north side of Pittsburgh are two limited access expressways which should be under construction before too many months pass by.

Since its creation in 1946, the Public Parking Authority of Pittsburgh has constructed over 3,900 parking spaces in five garages downtown, and now has plans under way for at least two more facilities downtown as well as lots and garages in four secondary districts.

Created in 1946, the Urban Redevelopment Authority has one of the most solid backgrounds of accomplishment of any redevelopment authority in the country. The twenty-three-acre Gateway Center commercial redevelopment, with the Equitable Life Assurance Society as redeveloper, was its first project. This was followed by another redevelopment on the south side of the Monongahela River in which Jones and Laughlin Steel Corporation spent \$70,000,000 in redeveloping the area and constructing a new mill. This project alone added 2,000,000 ingot tons per year to the city's steel producing capacity. Now the Authority has three more redevelopment projects under way, one of which, the Lower Hill redevelopment, will rip out 96 acres of slum to be replaced by a magnificent public auditorium, several high-rise apartments, and other public buildings. One of the major problems directly related to this redevelopment, the relocation of 1,850 families now living in the redevelopment area, is being handled by the City's Housing Authority. Without the 7,000 units of low-rent public housing provided over the past seventeen years by the Housing Authority, the relocation of these low-income families could not have been handled, and the massive redevelopment may have fallen by the wayside. In addition, the Redevelopment Authority is engaging in two redevelopment projects with the University of Pittsburgh, two more projects with the Jones and Laughlin Steel Corporation, and has plans for redevelopment at Duquesne University, East Liberty and North Side.

Also in the past ten years there has been an increasing surge of private development. In addition to those private developments already mentioned,

which were made possible through the land collection powers of the Urban Redevelopment Authority, many corporations have entered into construction on their own. The 41-story Mellon-U.S. Steel Building and the 31-story Alco Building face each other across the Mellon Square Park. The City's newest hotel, the Carlton House, was completed in 1951, and just this year Conrad Hilton has announced that he soon will begin to build a large hotel in Gateway Center facing Point State Park. Additional industries have come into the area with new plants, and many existing industries have enlarged their operations. However, it is realized that the City must diversify its industry to strengthen its economic base. The recently formed Regional Industrial Development Corporation has begun to tackle this important task. In the past ten years, four industries have constructed major research centers, while four others have begun construction or have announced plans to construct research centers. This new construction will make Pittsburgh a world leader in industrial research.

In the educational field, the University of Pittsburgh has embarked on an expansion program of major proportions. Construction of four new buildings in the Health Center alone totals $45,000,000. And this represents only part of the total expansion.

City recreational facilities have been advanced in the Arts and Crafts Center, a new Children's Zoo, and the construction of a new conservatory-aviary. The City, County and municipalities throughout the county have joined forces in the work of the Allegheny County Sanitary Authority to begin construction this year of a massive county-wide system of sewer interceptors and sewage treatment. When completed, the Sanitary Authority program will total approximately $100,000,000. Allegheny County itself has constructed the giant Greater Pittsburgh Airport costing $28,000,000 and next year will complete a new 2,200-bed institution district for the aged and infirm. And the County and State together have built or will build eight major bridges in the area.

Through this brief enumeration, one can see that the Pittsburgh Renaissance is not a one-agency movement, but has many facets and is promoted actively by official bodies and civic agencies together.

PENN-LINCOLN PARKWAY

Since this symposium deals primarily with the Penn-Lincoln Parkway, it should be pertinent to our discussion to examine the development of the parkway in order to discover how it was affected by the Pittsburgh Renaissance.

History

To the highway planner and city planner the Penn-Lincoln Parkway is a misnomer. It's not really a parkway at all, but a limited-access freeway open to all types of free-wheeling vehicles. The Penn-Lincoln Parkway is an east-west highway running through the heart of the city, with about 16 miles of its 19-1/2 mile length now completed. Two and one-half miles of very complicated interchange near the downtown area is well along in construction, and another mile, represented by the Fort Pitt Tunnel and Fort Pitt Bridge, for the most part remains to be built.

Although the Parkway has come to fruition in the last decade, the groundwork for it was laid painstakingly many years before. All of the early planning for this highway was done locally. In the years 1924 to 1935, citizens associations and the county and city planning commissions investigated and promoted a route which would be an easterly extension of the Boulevard of the Allies through the city. Although there was general agreement among the various proponents regarding the need for the highway to the east, there were differences of opinion on the best route. In 1935, studies of the county planning commission developed a proposed route which, for the most part, followed the route as it is now being constructed.

Extensions of the Penn-Lincoln highway west of the city were not studied until 1936. In that year, the county planning commission developed a location west from the Triangle roughly paralleling Campbell's Run Road to a point where it intersected routes 22 and 30. The present Parkway West follows this alignment almost exactly.

In 1937, the interest of the State Highway Department was developed when the Secretary of Highways and the Chief Engineer of the Department were conducted on a tour of the proposed Parkway location of City and County Officials and representatives of the Chamber of Commerce and the Penn-Lincoln Highway Association. After the tour, the State officials agreed that the Penn-Lincoln Highway project through the city should be adopted as part of the State's program. The District Engineer of the State with the technical cooperation of the County Planning Engineer continued further route studies. A short time later the project was presented to the United States Bureau of Public Roads for consideration.

The Pittsburgh Regional Planning Association, 1939, retained Robert Moses to prepare a highway plan for the City of Pittsburgh. In his report, Mr. Moses endorsed the Parkway East and recommended a location quite similar to that previously suggested by the County Planning Commission.

In November, 1941, the U.S. Public Roads Administration and the State agreed to contribute matching funds for surveying and planning the parkway. And in 1943, an engineering firm was retained by the State to prepare contract plans for the Parkway East, although it was realized that construction could not get underway until the end of World War II.

After the organization of the Allegheny Conference in 1943, the Penn-Lincoln Parkway was adopted as part of the Conference program, and its officials promoted the project actively in the next few years. Finally, in November, 1945, the Governor announced a $57,000,000 improvement program for the Pittsburgh district. The two major projects in this improvement program were Point State Park and the Penn-Lincoln Parkway. From this time on, the Parkway project moved ahead rapidly, and in July, 1946, ground was broken for construction of the most easterly portion of the Parkway East.

Coordination During Construction

Local interest in the Parkway both on the part of official and civic planners did not dwindle after the start of construction but, rather, was intensified. Although the Parkway location generally had been determined, contract plans were completed for only the first six miles on the east, and many

decisions remained concerning the integration of the Parkway with other elements of the City's development, particularly in the downtown district.

In a central city district as constructed as Pittsburgh, it is only natural that many of the problems of Parkway coordination would occur in this area. And the most knotty of all these problems occurred at the point of the Triangle where the Point interchange will cut through Point State Park.

The local guiding group for Point State Park is the Point Park Committee of the Allegheny Conference, formed in November, 1945, at the suggestion of the State. Since the primary concern of this Committee was the development of the best possible park, it naturally was vitally interested in the type of highway interchange which would be built, assuring itself that the interchange would be as small a barrier as possible to an integrated park plan, and that the interchange occupied a minimum of the 36-acre park. Much time was spent on study and deliberation both by representatives of the State Highway Department and the Point Park Committee to produce an acceptable interchange design. Finally, the development by the State's Consulting Engineer of a direct movement interchange through double-decking the bridges across the two rivers provided the happy solution of the best interchange for the park interests and the highway interests as well. In the park design, the landscaping and grading is planned in such a manner that much of the interchange will be obscured. The central portion of the interchange will be bridged, acting as an architecturally treated "portal" for the main part of the park.

Because it was realized that the demolition and complete redevelopment of the 58 acres in the Lower Triangle to be occupied by Gateway Center, Point State Park, and the Point Interchange would have to be planned and controlled quite carefully, Conference leaders prevailed upon the Governor to create a Point Coordinating Committee and appoint an active officer of the Conference as chairman, with the chairman having power to select committee members. The Committee met first in March, 1950, and determined that its function should be the coordinating and planning for solution of its mutual problems as concern more than one agency. For four years the Point Coordinating Committee met periodically, and effectively coordinated the work of the many agencies, public and private, in this complicated undertaking. For the past two years the Committee has had no reason to meet, but soon, when interchange construction and park completion work gets underway, it will become active again, looking for trouble that it might prevent.

Another group having a direct bearing on the Parkway has been a committee with the ponderous title of "The Mayor's Emergency Committee on Traffic Flow During Construction." This committee was appointed in August, 1951, by the Mayor and has represented on it City, County, and State officials responsible for planning, traffic movement, and construction as well as representatives of various civic organizations. The Executive Director of the Allegheny Conference is chairman of this committee. The function of the Committee on Traffic Flow has been to plan and carry through the movement of traffic in those areas affected by new highway construction. The committee has been helpful particularly during the various phases of construction of the Penn-Lincoln Parkway, East and West. Because of the Parkway's crossing, parallelling, and tying into existing traffic arteries, the work of this committee in coordinating new construction with the handling of traffic has advanced the progress of the work considerably.

Another knotty problem in the Parkway progress was represented by the Baltimore and Ohio Railroad whose entire complex of terminal facilities—passenger station, freight warehouse and railroad years--lay directly athwart the new location of the Penn-Lincoln Parkway on the eastern edge of the downtown district. Here again, the Allegheny Conference was the prime catalyst in making it possible for the Railroad and the State Highway Department to reach an amicable agreement after several years of negotiation. Now the B. & O. is in the process of relocating, and soon the parkway constructors will move into present railroad property.

A final example of local unofficial coordination and effort blending with official actions to produce a better end result, is represented by the story of the landscaping and roadside control of signs for the Parkway. In 1947, the State Department of Highways found that it would not have any funds in the foreseeable future for the preparation of plans for landscaping the Parkway. The leaders of the Pittsburgh Regional Planning Association at this time felt quite strongly that a limited-access highway of this magnitude not only should be landscaped to protect it from erosion and enhance its beauty, but also should have roadside signs controlled in order to develop the full effect of the landscaping. Therefore, Regional Planning Association engaged a firm of landscape architects to prepare landscaping plans for the full length of the parkway and to work out three plans so that they would be acceptable to the Highway Department and the Bureau of Public Roads. Shortly after the landscaping plans were completed, the State discovered that it could do much of the landscaping using its own funds and federal funds. At this time, the proposed landscaping work was divided into three catagories: erosion control, essential ornamental, and desirable ornamental. Pittsburgh Regional Planning Association agreed to undertake the planting of as much of the desirable ornamental as possible through interested garden clubs and other agencies. At the present time, seven local garden clubs have provided funds to plant various sections of the Parkway with those trees and shrubs listed as desirable ornamental. Coincident with the beginning of the landscaping effort, Regional Planning Association conducted a study of zoning ordinances of the seventeen municipalities through which the Parkway passed to determine whether it would be protected adequately from sign encroachment. The study showed that six municipalities either had no zoning whatever or had zoning ordinances which were inadequate. Meetings were held with officials of all six municipalities, and in every instance except one a zoning ordinance was enacted or the existing ordinance corrected to protect the parkway from blatant billboards. Now, with the Parkway West completed, one can easily detect which community did not pass a zoning ordinance to protect the Parkway, since the only portion unprotected is a short one-mile length near the Greater Pittsburgh Airport which is packed with advertising billboards. With the remainder of the Parkway having no billboards, any disinterested motorist may see the difference and decide for himself whether roadside control of signs is desirable.

Recapitulation

When one examines this concerted effort to remake the metropolitan City of Pittsburgh into something better than it was, one finds that it resulted from a fortunate combination of several factors.

First, there existed a genuine desire on the part of the entire community to do something in the way of improvement. Conditions were bad and growing worse, and it was realized that the trend had to be reversed. In any city this same kind of desire must be felt before any community program can be successful.

Second, top level men in the community, both in public life and in private enterprise, exerted, and still are exerting, their own personal effort for the community. The assistant to the president of a major corporation is not the person who is assigned to discharge a civic obligation. Rather, it is the president himself. Also, political differences have been set aside in those functions which pertain to the Pittsburgh Program with various factions working side by side toward a common goal. In another community, the form of organization employed to coordinate these activities could be a secondary consideration. Of greater importance is the fact that the efforts come from the top and have some direction.

Third is that basic problems were tackled first. For Pittsburgh, these basic problems were smoke and flood. The successful smoke control and flood control programs were dramatic examples that something really could be done, and other problems which at one time seemed insurmountable soon were being tackled without trepidation.

Fourth, in seeking a solution, the ultimate goal has been kept in mind. But with it, there has been a willingness to compromise, possibly to accept something less than an ideal solution in order to give an end product which still is infinitely better than the condition as it existed. Unfortunately, for many planners, this willingness to compromise is an extremely difficult process. Too many times, city planners cling to their own carefully developed plans which are sacred to their own minds, and will accept nothing less. Often, as a result, nothing is done.

Finally, there has been a general continuity of committee membership in which most key officials are represented on practically all groups pertaining to the Pittsburgh Program. In this way, these key people can see the broad picture of development, and can more readily coordinate the various activities in which they may be involved. Coupled with this is the fact that the professional planners have not retired from the scene upon completion of their plans, but have remained in the forefront, bringing the plans into action.

There is no magic formula to this business of making a better city. It can come only through hard work and determination among men of good will. The several factors just described really are fundamental and common-sense for any kind of group endeavor. Unless the leaders in a community recognize this, there is little opportunity for much accomplishment.

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

TESTS TO EVALUATE CONCRETE PAVEMENT SUBBASES

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(Proc. Paper 1297)

SYNOPSIS

An investigation designed to aid in evaluating the contribution of subbases under concrete pavements to the strength of the roadway structure was inaugurated by load-testing concrete panels built on five different foundations. One subgrade was a 4-ft. deep bed of high-bearing-value sand and gravel, a second was a low-bearing-value clay 5 ft. deep, and three foundations consisted of well compacted dense graded sand and gravel subbases of thicknesses 3, 6, and 12 in. placed upon the deep clay subgrade.

Upon these foundations, plain concrete slabs 10 ft. by 15 ft. by 6 in. were cast and instrumented to register strains in the concrete, panel deflections, and vertical pressures at the slab-subbase and subbase-subgrade interfaces. Static loads were applied to these panels at the corners, edges, and interiors. The data obtained from tests conducted when the panels were "flat"—i.e., fully in contact with the supporting soil—showed the extent to which the granular subbases contributed to the strength of the pavement structure. The effect of slab curl will be discussed in later reports.

In the critical corner and edge areas, strains decreases 25% as the subbase thickness was increased to 12 in., and deflections were reduced 50% and 30%, respectively. Pressures directly beneath the slab on top of the subbase, became greater as the subbase thickness increased, but pressures on the subgrade were reduced. For a 6-kip load and 12-in. subbase, the pressures under edge loading were 5 psi on the subbase and 2 psi on the subgrade. Similarly, under interior loading the pressures were 2 and 1 psi, and at free corners were 17 and 12 psi at the two interfaces.

Note: Discussion open until December 1, 1957. Paper 1297 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 83, No. HW 3, July, 1957.

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An analysis based on measured load-strain and load-deflection relations under edge loadings and on close-fitting theoretical curves shows that:

1. The stresses induced in a 6-in. slab on a 6-in. well compacted, dense-graded subbase were the same as would be expected in a 6-1/2 in. slab with no subbase; and the stresses in a 6-in. slab on a 12-in. subbase were the same as would be expected in a 7-in. slab with no subbase.

2. The deflections of a 6-in. slab on a 6-in. subbase were the same as would be expected with a 7 1/2-in. slab with no subbase; and the deflections of a 6-in. slab on a 12-in. subbase were the same as would be expected with an 8-in. slab with no subbase.

A comparison of measured strains and deflections with theoretical values computed using Westergaard's theory generally showed reasonably good agreement although measured values in many cases were more sensitive to changes in subgrade support than the theory indicated.

The study of subbase effects is being continued. Reports on 8-in. slabs supported by open-textured sand and gravel subbases will follow. This series will include data on both flat and curled slabs.

INTRODUCTION

Much experimental and theoretical work has been done in the field of concrete pavement design since the early twenties. Among the better known studies are the Bates Road Test,(1) the Bureau of Public Roads Arlington tests,(2) Westergaard's(3) analyses, the U. S. Army Engineers Lockbourne tests,(4) and Road Test One-Md.(5) Important contributions have been made by universities and highway departments.

Today, concrete pavements are designed primarily from the findings of these studies. The Westergaard theory is the dominant influence in design. It is usually used with slight modifications introduced because of the tendency for concrete panels to curl away from the foundation materials. Other design methods based upon the assumption of elastic layered systems are being seriously considered, but have not been readily accepted because of their complexity and lack of experimental confirmation.

A principal problem associated with the most economical design of concrete pavements to withstand heavy axle loads has to do with the effect of subbases on the performance of the pavement. Subbases are required in areas in which the subgrade may be severely weakened by frost melting or where it is susceptible to pumping, a process in which fine-textured subgrade soils become suspended in water and are pumped from under the slab by the action of heavy traffic. Pumping reduces subgrade support in local areas and causes non-uniformity in bearing. To correct this situation and in some cases to improve the load-carrying capacity of the foundation, subbases, usually of granular materials, are built upon the subgrade. The thickness of subbase used by various construction agencies varies from 3 in. up to 12 in. or more. Experimental roads have been built and are now under test to investigate the effect of thickness on highway performance, particularly from the standpoint of preventing pumping.

A layer of well compacted granular material is known to have an inherent

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* Figures in parentheses refer to bibliography.

ability to support a load. Thus, a subbase built on a fine-grained subgrade primarily for pumping control doubtless also contributes directly to the pavement strength if the subbase is properly compacted to prevent further densification.

The principal purpose of this investigation is to develop performance criteria to be used as a basis for evaluating the strength contributions made by subbases to the pavement structure. The data will aid in determining whether a subbase thicker than that required to prevent pumping is structurally economical. Ultimately, these tests will permit the development of concrete-slab-thickness to subbase-thickness relationships that will enable the engineer to select the most economical and effective design for a particular traffic condition.

Scope of the Program

The tests reported at this time were made with 6-in. concrete panels 10 by 15 ft. in size built upon dense-graded sand and gravel subbases; other subbase materials and slabs of different sizes will be tested. The next series of tests will be made on twin 8-in. panels 12 by 18 ft. in size, doweled along an 18-ft. edge, built upon open-textured sand and gravel. Following these tests, crushed limestone subbases will be tested to study the influence of particle shape. Other subbase materials programmed are granular and plastic soils treated with cement.

This test program on isolated flat slabs provides information for evaluating the strength contribution to a concrete pavement of subbases of different types and thicknesses. Also, the data will supplement available information on Westergaard's equations for calculating strains and deflections in pavements.

It is recognized that an unrestrained flat concrete panel is not equivalent to a highway slab that is restrained at both ends by dowels and possible end thrust and subject to vertical movement due to curl. However, the results from the controlled tests in the laboratory are now being correlated with field tests on highways in service to obtain supplementary material for evaluating subbases in actual use.

This report includes initial tests of one slab built on a dense sand and gravel subgrade and of one slab built on a clay subgrade. These two extreme conditions of subgrade support were selected to give the limiting values of deflections, pressures, and slab strains between which values for other slabs constructed with subbases would probably lie. Data are also reported on slabs supported in 3-in., 6-in., and 12-in. sand and gravel materials placed on the clay subgrade.

Specific Objectives of the Program

The investigation is being pursued with the following specific objectives:

1. To determine effect of thickness of subbase on the load-carrying capacity of the slab.

2. To investigate effect of subbases in distributing pressures to the subgrade.

3. To obtain information helpful in establishing relationships between slab thickness and subbase thickness to effect economy in pavement design when strong foundations are specified.

4. To compare experimental load-strain-deflection relationships with those computed in accordance with the theory that deflection is everywhere proportional to pressure, as in the Westergaard theory.

TEST METHODS AND MATERIALS

Facilities

The testing area, 24 by 37 ft., adequate to contain two concrete panels, is enclosed in a concrete building equipped with thermostatically controlled heaters to provide a uniform temperature during the heating season. The area was excavated 4 ft. below grade to the bottom of the wall footings and a 5-in. reinforced concrete floor was cast. An expansion strip was installed to separate the floor from the walls, thus assuring that the floor would transmit stresses readily to the soil below. A shielded membrane waterproofing treatment was applied to the floor and walls to protect the subgrade from moisture changes.

A 6-in. wood partition separated the area into two 18 by 24-ft. test pits, which were filled with subgrade soils to a depth of 4 to 5 ft. Shoulders approximately 4 ft. wide surrounded the 10 by 15-ft. test panels.

The subgrade depth was selected on the basis of studies by Pickett(6) which showed that a subgrade depth equal to twice the radius of relative stiffness of the roadway structure would result in panel strains 95% as great as if the depth were five times this radius, and in deflections 80% as great. The radius of relative stiffness for these studies ranged from 24 to 30 in., so a test pit 4 to 5 ft. deep was adequate.

To provide reaction to static loads, overhead steel frames were installed over the test areas as shown in Fig. 1. The main girders were 14-in. wide-flanged beams, and suspended below these were 8-in. transverse beams. Trolleys at each end of the transverse beams permitted them to be placed above all parts of the working area. A third trolley traveled along the transverse beam and from this was suspended a pipe column to which a hydraulic jack was attached.

Materials

One test pit was filled to a depth of 4 ft. with a high-bearing-value sand and gravel; the other pit was filled to a depth of 5 ft. with a low-bearing-value clay. Some of the granular material used in the first pit was later moved to the second pit to form a subbase over the clay.

Granular Subgrade and Subbase Material

The granular subgrade and all the subbases were built with a bank run sand and gravel modified at the time of placement by adding stripping soil and a small amount of coarse gravel. Gradation and subgrade soil constants of this material are listed in Table 1, and AASHO moisture-density relationships and unsoaked C.B.R.* values are shown in Fig. 2. These tests show that the

* "Suggested Method of Test for California Bearing Ratio of Soils," Procedures for Testing Soils, ASTM July 1950.

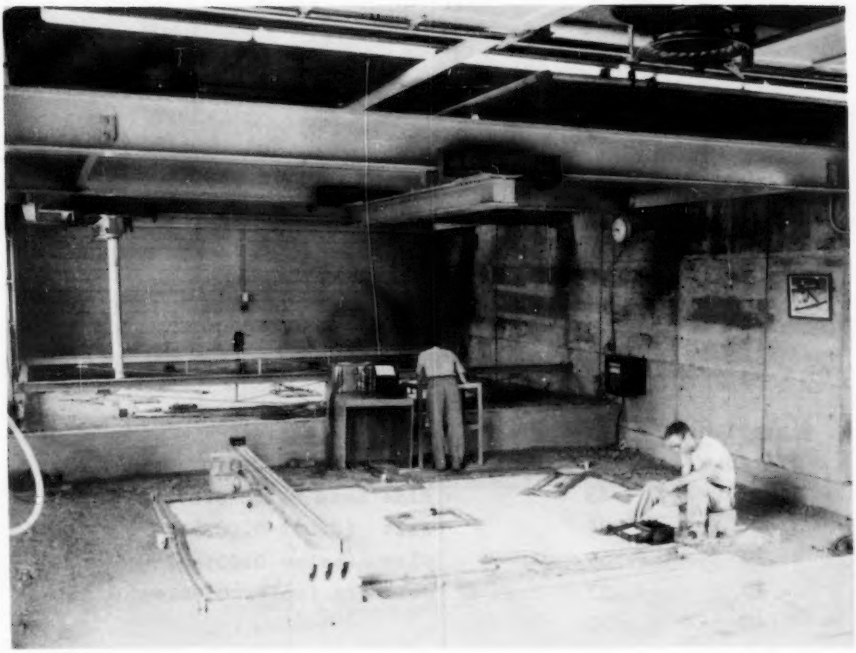


Fig. 1 - General View of Test Area. Reaction beams are overhead with loading column and longitudinal trusses to support deflection bridge in background. Dikes on panels are for water retention to maintain slabs in a flat condition.

Table 1

GRADATION AND LIMITS OF SUBGRADE AND SUBBASE MATERIALS

GRANULAR		CLAY	
GRADATION			
Sieve	% Passing	Particle Size	%
3/4 in.	100	Coarse Sand (2.0-0.42mm)	4
1/2	83	Fine Sand (0.42-0.074mm)	16
3/8	79	Silt (0.074-0.005mm)	40
No. 4	69	Clay (below 0.005mm)	40
10	53	Colloids (below 0.001mm)	20
40	30		
200	12		
SUBGRADE SOIL CONSTANTS			
Liquid Limit	23	Liquid Limit	48
Nonplastic		Plasticity Index	24
MOISTURE-DENSITY RELATIONSHIPS, AASHO T99-45			
Maximum Dry Density*	131 pcf	Maximum Dry Density	105 pcf
Optimum Moisture*	8.5%	Optimum Moisture	20.4%

* Includes No. 4 to 3/4 aggregate in the test specimen.

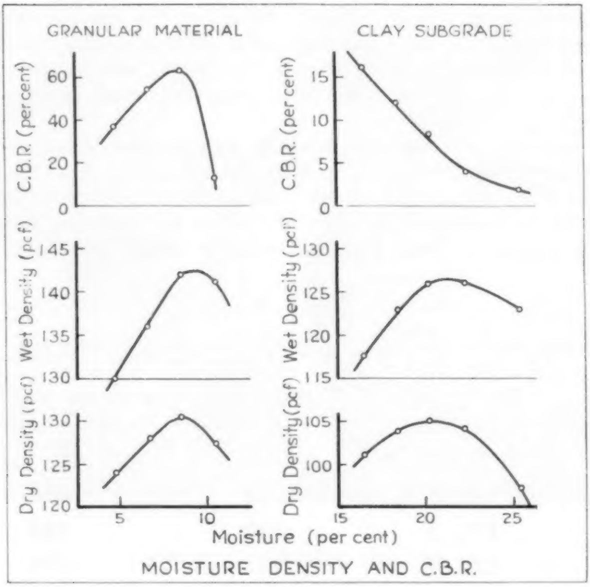

GRANULAR MATERIAL
CLAY SUBGRADE
C.B.R. (per cent)
Wet Density (pcf)
Dry Density (pcf)
Moisture (per cent)
MOISTURE DENSITY AND C.B.R.

FIG. 2

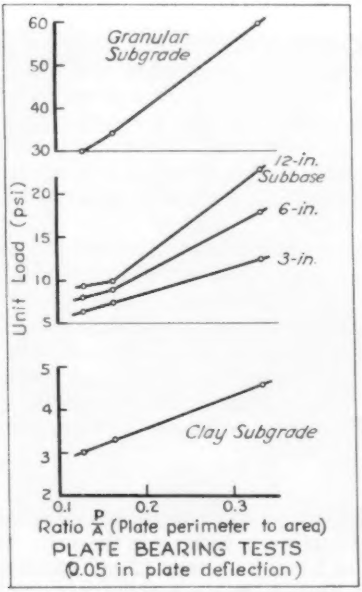

Granular Subgrade
12-in. Subbase
6-in.
3-in.
Clay Subgrade
Unit Load (psi)
Ratio $\frac{P}{A}$ (Plate perimeter to area)
PLATE BEARING TESTS
(0.05 in plate deflection)

FIG. 3

C.B.R. was greater than 50 when the material was compacted near optimum moisture and maximum density.

The material for the deep granular subgrade was placed in 6-in. lifts and compacted at a moisture content slightly below optimum to approximately 96% maximum density by a combination of tamping and vibrating with equipment illustrated in Figs. 4 and 5.

Control tests on each one-foot layer of the sand and gravel included in-place density and moisture tests, and the determination of k—the modulus of subgrade reaction—by bearing plates. These tests were made with 12-in., 24-in., and 30-in. diameter plates. The control data obtained are given in Table 2, and the top curve of Fig. 3 shows plate-bearing values.

Table 2

CONTROL TESTS ON SAND AND GRAVEL SUBGRADE

Layer	In-Place Dry Density, pcf	Moisture Content, %	k from 30" Plate 0.05" Deflection, pci
1	126.5	8.3	672
2	127.5	7.8	622
3	124.0	7.4	575
4	126.8	7.3	573

Clay Subgrade Soil

The gradation and plasticity characteristics of the clay soil are given in Table 1 and the associated moisture-density relations and C.B.R. values are shown in Fig. 2. The soil was prepared for placement by spreading a quantity on a concrete apron, breaking it up with a rotary tiller, and mixing sufficient water with it to attain approximately 23.5% moisture. (According to Fig. 2 the soil had a C.B.R. of about 2.5 when tested at this moisture content.) It was then compacted with the tamping rammer in 4-in. to 6-in. lifts to a depth of 5 ft.

To assure reasonable uniformity, in-place density and moisture tests and plate-bearing tests were made on each one-foot layer. Results of the control tests are given in Table 3. Plate-bearing value data are plotted in Fig. 3. Although the control k value on layer 5 was 65 pci, this figure had become 100 pci at the start of the routine tests. Some time elapsed between the completion of subgrade construction and the beginning of routine because of pilot studies for the development of test techniques, and the resulting moisture loss contributed to the increase in k. Moisture barriers prevented further changes.

Subbases

After the concrete panel test was completed on the deep clay subgrade, subbases of the sand and gravel were built upon the soil. They were placed in compacted thicknesses of 3 in., 6 in., and 12 in. Moisture, density, and plate-bearing test results are given in Table 4; plate-bearing test data are plotted in Fig. 3.

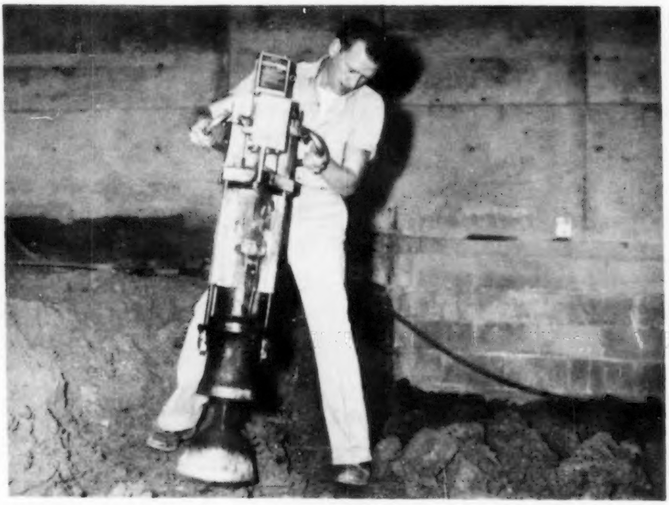


Fig. 4 - Rammer Compacting Cohesive Subgrade.

Fig. 5 - Vibrator on Sand and Gravel

Table 3

CONTROL TESTS ON THE CLAY SUBGRADE

Layer	In-Place Dry Density, pcf	Moisture Content, %	k from 30" Plate 0.05" Deflection, pci
1	100.8	23.3	--
2	102.1	23.0	54
3	103.0	23.8	54
4	101.7	23.9	60
5	101.5	24.1	65

Table 4

TESTS ON SUBBASES

Thickness, in.	In-Place Dry Density, pcf	Moisture Content, %	k from 30" Plate 0.05" Deflection, pci
3	128.8	7.5	120
6	129.2	7.7	145
12	131.9	7.8	170

Concrete Panels

The dimensions of all slabs in this series were 10 ft. by 15 ft. by 6 in. Natural sand and gravel aggregates from one source were used. The sieve analyses are given in Table 5. The cement factor for the concrete was 6 sk. per cu. yd., the water-cement ratio by weight was 0.48, air content was approximately 5%, and the slump was approximately 3 in. The concrete was placed in 6 cu. ft. batches, carefully vibrated around the instrumentation, and surface compacted with a vibrating screed. Standard 6 by 12-in. cylinders, 6 by 6 by 36-in. beams, and special 12 by 6 by 42-in. beams were cast during the placing of the mix. The concrete panel and the large beams, cast on the subgrade adjacent to the panel, were cured under wet burlap for 14 days. The other test specimens were cured in steel molds overnight and then placed in a fog room until tested.

The cylinders and 6 by 6-in. beams were tested by the sonic method at several ages to determine the elastic modulus, E. They were then broken in compression and flexure. The 6-in. thick by 12-in. wide beams were subjected to the same curing as the slabs, and were tested in-place with a device which applied loads at the third points. A typical record of concrete test data is shown in Table 6.

Table 5

CONCRETE AGGREGATE GRADATION

Coarse Aggregate Sieve	% Passing	Fine Aggregate Sieve	% Passing
1-in.	100	No. 4	98
3/4	89	8	86
1/2	71	16	68
3/8	48	30	44
		50	21
		100	4

Table 6

CONCRETE PROPERTIES

Specimen	Age, days	Strength, psi Compression	Flexure	E, million psi
6x12-in.	14	4570	-	4.75
Cylinders	28	5905	-	5.07
	150	8400	-	6.36
6x6-in.	14	-	610	5.12
Beams	28	-	680	5.75
	150	-	1030	7.85
6x12-in.	14	-	-	5.52*
Beams	28	-	-	6.57*
	150	-	906	7.80*

* Indicates E by static deflections.

Instrumentation and Equipment

Instrumentation was provided to compare pressure, strain and deflection relationships at various loads. Other quantities measured were soil moisture, slab and soil temperatures, and curling deformation of the slabs.

Pressure Cell Instrumentation

Pressures directly beneath the slab and at the subbase-subgrade interface were determined with Carlson stress meters.(7) For pressure measurement

directly beneath the slab the meters were installed with the sensing elements upward as shown in Fig. 6. To obtain uniform distribution of pressure on the meter, mortar was used to bed a 3/4-in. thick, 9-in. diameter steel disk on the soil; then a neat cement paste was placed between the disk and the stress meter diaphragm. An improved stress meter was obtained for some of the later tests and the auxiliary disk was not necessary. The 7 1/4-in. diaphragm plate on these meters was bedded directly onto the soil with a thin mortar layer.

For pressure measurement between the subbase and subgrade, the stress meters were installed in a mortar bed with the stem downward, care being taken to exclude all air beneath the meter. A length of sponge rubber weather-stripping material was wrapped around the circumference of the diaphragm to assure unrestricted action. A small quantity of neat cement paste was placed in the center of the stress meter diaphragm and a 3/4-in. thick steel disk of the same diameter as the cell plate was pressed in place over the cell until paste was extruded completely around the circumference and there was reasonable certainty that the paste layer was free from voids. A ten-pound weight was placed upon the disk to assure continuous contact while the cement was setting. Instrument constants were furnished by the manufacturer and check tests on the calibration curve were made after the stress meter had been installed to assure proper response.

The arrangement of pressure cells beneath the panels is illustrated in Fig. 8. Slabs 1 and 2 had no subbase and hence no subbase pressure cells. Cells 2, 4, and 12 were omitted in Slabs 3, 4, and 5.

Strain Gage Instrumentation

Although surface strain measurements on top of the slab were satisfactory for determining critical stresses in concrete panels when loads were applied at the corners, they could not be used to determine critical tensile stress at other positions without assuming uniform stress gradient and constant neutral axis. Therefore, some other method of measuring strains near the top and bottom of the slab was needed. For this purpose a strain measuring capsule[8] suitable for embedment in the panels was developed (Fig. 7).

The housing for the strain capsule was steel tubing of 1/2-in. diameter and 0.05-in. wall thickness. This produced an effective modulus for the capsule less than twice that of the concrete. A 6-in. length gave a length-to-radius ratio of 24. Two SR-4 type A-12 gages were cemented longitudinally to the inner walls of the tube in diametrically opposed positions. The two gages were wired with a common ground, and the ground wire was soldered to a 3/16-in. copper tube which housed the other two wires. The tube was fastened to the capsule at the center of one of the turned steel plugs. After assembly the unit was heat-cured and the copper tube plugged with a wax-type waterproofing compound. The strain capsules were supported above the subbase by wire frames (Fig. 6) to prevent shifting of the assembly while the concrete was being placed.

Surface strain measurements were made at a number of locations on the top surface of each panel. SR-4 type A-9 gages were cemented to the concrete after the area had been prepared by grinding.

Locations of embedded capsules and surface strain gages are shown in Fig. 8. The dimensions on the surface gage layout are representative and are not necessarily exact for all panels. During testing of the slabs, good agreement was obtained between surface gage readings and the extrapolated values

Fig. 6 - Carlson Pressure Cells on Subbase

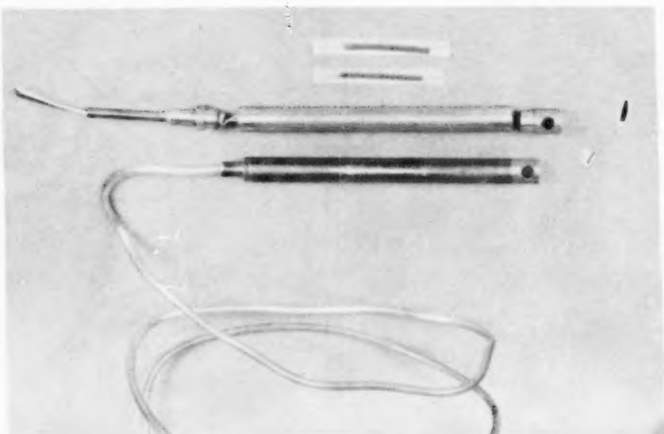
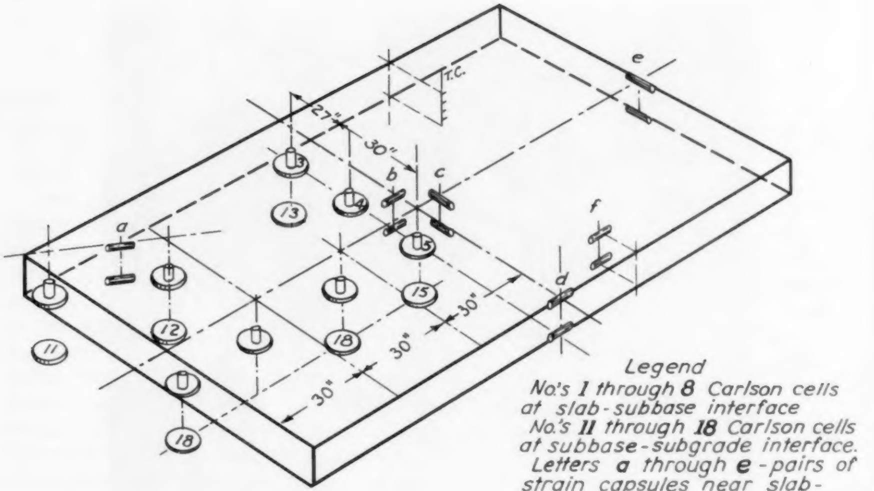
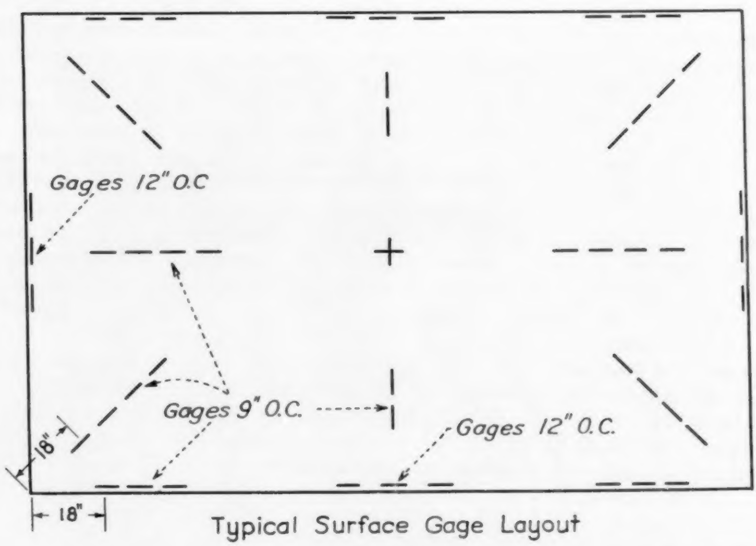


Fig. 7 - Strain Capsule for Embedment in Concrete



Phantom View of Internal Instrumentation



Typical Surface Gage Layout

INSTRUMENTATION OF PANELS AND SUBBASES

FIG. 8

from the embedded capsules. Only in a few instances were variations as great as 10%. Capsules in the bottom of the slab at the edge and interior gave strain magnitudes averaging about 5% less than those in the top where a direct comparison was possible. Since the two methods of measuring strains agreed closely, only the data obtained with the SR-4 surface gages are reported.

The positions of the thermocouples which were placed vertically through the slab to indicate temperature differences are shown in Fig. 8.

Deflection Measuring Devices

Deflections due to load were measured with 0.001-in. dial indicators supported by a wood bridge resting on longitudinal trusses fastened to the reinforced concrete building walls. The stems of the dials contacted the slab surface on 3/4-in. diameter hardened copper rivet heads embedded in grid pattern in the concrete surface. The deflection-measuring equipment is shown in Fig. 9.

Loading Devices

Loads were applied to the panels by 10-ton hydraulic jacks. The threaded top of the piston was fastened to a length of 3-in. pipe which in turn was held in place by a flange fastened to the overhead trolley. A fitting adapted the

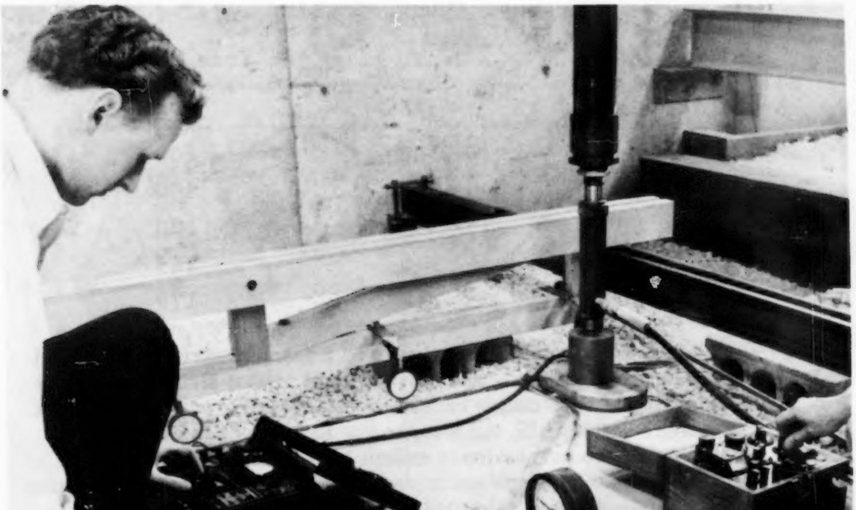


Fig. 9. Load test at corner. Note use of load cell, pressure indicator, and deflection bridge.

bottom of the jack to a load cell(9) which was connected electrically to a strain indicator to show load intensity.

A 70-sq. in. oval plate resting on a rubber pad was used to simulate a tire for wheel load application.

TEST DETAILS AND RESULTS

Load-Deflection-Strain Relations

The data presented were obtained under "single wheel" loading at four positions: (1) interior loading at the center of each panel, (2) edge loading at the middle of a longitudinal (15-ft.) edge, (3) corner loading, and (4) edge loading at the middle of a free transverse (10-ft.) edge. In all cases the long dimension of the loading area was parallel to the longitudinal center-line of the panel. Two or three "seating" loads were applied before the deflections and strains were recorded. Repetitive loadings up to 100 cycles showed that deflections were elastic and that replicate load tests checked very closely within this range of repetitions.

Identification of the test slabs and foundation k values are given in Table 7.

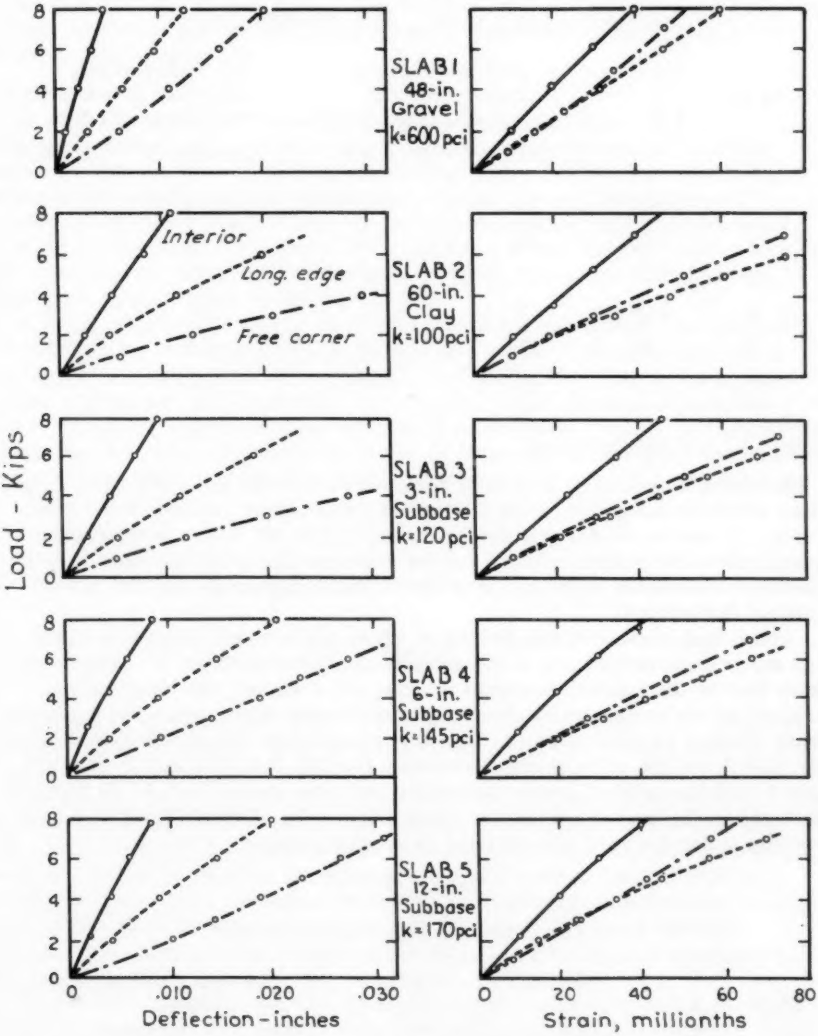
Table 7

SLAB NUMBERS AND FOUNDATION DATA

Slab No.	Depth of Clay, in.	Depth of Gravel, in.	k from 30" Plate 0.05" Deflection pci
1	0	48	600
2	60	0	100
3	60	3	120
4	60	6	145
5	60	12	170

A summary of the maximum deflections and maximum strains measured under interior, longitudinal edge, and corner loads on flat slabs is shown in Fig. 10. It is seen that deflections caused by edge loads always lie between interior and corner deflections, but strains due to edge loads are slightly greater than those due to corner loads except for the smaller loads.

The ratios of interior-to-edge and corner-to-edge deflections and strains were computed for 4-, 6-, and 8-kip loads and the averages are given in Table 8. The interior-to-edge deflection ratio remains constant at about 40% for all panels except Slab 1, but the corner-to-edge ratio decreases as the subbase thickness increases showing that in these tests corner deflections are affected more by subbases than interior or edge deflections. The interior-to-edge strain ratio is slightly higher for Slab 1 on the deep granular subgrade than for the other panels, but this trend is not followed at the corner, where the strain ratio is practically constant at 88% for all slabs.



EXPERIMENTAL DEFLECTIONS AND STRAINS

FIG. 10

Table 8

RELATIVE MAGNITUDES OF DEFLECTIONS AND STRAINS FOR INTERIOR, EDGE, AND CORNER LOADS

Slab	k, pci	Deflections, per cent of Edge Value		Strains, per cent of Edge Value	
		Interior	Corner	Interior	Corner
1	600	35	160	60	88
2	100	41	240	47	85
3	120	40	246	51	91
4	145	41	190	46	86
5	170	41	190	53	88
Av.	-	40	207	51	88

Critical Load and Deflection

A concrete pavement is usually designed so that the applied loads will produce stresses not greater than one-half the modulus of rupture of the concrete. A safe figure for this design stress is 325 psi, which is approximately equivalent to 54 millionths strain in the concrete panels of this test. The deflections associated with strains of this critical magnitude may be called critical deflections.

Loads that cause critical strains at edges and corners of the test slabs and the critical deflections at these loads are listed in Table 9. These data show that as the subbase becomes thicker, and k higher, the load to cause critical strain increases but the critical deflection decreases. For instance, loads causing critical stress in Slab 1 are more than 50% greater than those for Slab 2, but the critical edge deflection for Slab 2 is 27% higher than for Slab 1, and the critical corner deflection is double that of Slab 1. Critical deflections in the corner region are more affected by subbase thickness and corresponding changes in k than are those at the edges.

Table 9

CRITICAL LOADS AND DEFLECTIONS

Slab	k pci	Critical Load, lb		Critical Deflection, in.	
		Edge	Corner	Edge	Corner
1	600	7000	8300	0.011	0.021
2	100	4500	5300	0.014	0.042
3	120	4700	5400	0.014	0.040
4	145	5000	5800	0.013	0.030
5	170	5800	6700	0.013	0.030

Comparison of Experimental and Theoretical Values

The prevailing theory for concrete pavement design was developed by Westergaard, and his equations and modifications have been used for calculating theoretical strains and deflections for comparison with values measured in this investigation.

Development of Formulas

In 1926 Westergaard[3] developed equations for maximum stress and maximum deflection in concrete slabs using the assumption that reactive pressure under a slab is everywhere proportional to deflection. He further assumed the proportionality factor to be constant for a given subgrade. (These assumptions apply if the soil behaves as a dense liquid; accordingly, Westergaard's theory is sometimes referred to as the "dense liquid theory.") The formulas are numbered 1 through 6 in Table 10 and are listed in the simplified form derived by Bradbury.[10]

In 1933, after experimental data had become available from the Arlington tests indicating that experimental stress values were less than theoretical values for interior loads, Westergaard[11] discussed the effect of a redistribution of subgrade reactions under interior loads and developed formulas 7 and 8, which yield values somewhat less than formulas 1 and 2. In these 1933 equations, Z is the ratio of the reduction in deflection afforded by redistribution of pressures to the original deflections by Eq. 2; and L_1 is a multiple of L. The limits of Z and L_1 are: $0 < Z < 0.39$ and $L < L_1 < 5L$. For the Arlington tests $Z = 0.05$ and $L_1 = 1.75L$.

Another modification of the interior load equations appeared in 1939 in a discussion of stresses in airport pavements.[12] A term

$$S_2 = \frac{3(1-u)}{64} \frac{P}{h^2} \left(\frac{r}{L}\right)^2$$

was derived. This is to be added to the stress of formula 1. The correction is significant for large loading areas and high loads but is negligible for highway loadings.

It was also found in the Arlington tests[2] that strains measured at corners and edges indicated stresses greater than those computed by the 1926 formulas. Westergaard[13] then developed a method for computing stresses at corners not fully supported by the subgrade, but the method was not well received because of the estimates involved. An empirical modification of Eq. 5 was suggested by Bradbury,[14] a second by Kelley,[15] and a third by Spangler.[16] Kelley also suggested that edge Eq. 3 be altered as shown in Eq. 9.

Pickett[17] compared the effects of Bradbury's, Kelley's, and Spangler's suggestions and derived another corner formula listed here as Eq. 10. This formula has a theoretical basis but is simplified by approximation.

In 1943 the Westergaard[18] analysis was adapted to slabs supported in different ways and loaded with areas other than circular. This study was the basis for new formulas for stresses and deflections in airfield pavements,[19] which appeared in 1947. Eqs. 11, 12, and 13 are the 1947 equations expressed in terms of L, and Eq. 14 is reduced from the general form to give the deflection at the edge.

Other methods for computing stresses based on the "elastic theory" have

Table 10

DESIGN EQUATIONS

Position	No.	Maximum Stress, psi
Interior	1.	$S_i = S_1 = 0.275\,(1+u)\,\frac{P}{h^2}\,(4\log\frac{L}{B} + 1.069)$
Edge	3.	$S_e = 0.529\,(1+0.54u)\,\frac{P}{h^2}\,(4\log\frac{L}{B} + 0.359)$
Corner	5.	$S_c = \frac{3P}{h^2}\left[1+(\frac{r\sqrt{2}}{L})^{0.6}\right]$
Interior	7.	$S_i = S_1 - 15(1+u)\,\frac{P}{h^2}\left(\frac{L}{L_1}\right)^2 Z$
Edge	9.	$S_e = 0.529(1+0.54u)\,\frac{P}{h^2}\,(4\log\frac{L}{B} + \log B)$
Corner	10.	$S_c = 4.2\,\frac{P}{h^2}\,(1 - \frac{\sqrt{rL}}{0.925L+0.22r})$
Interior	11.	$S_i = 0.275(1+u)\frac{P}{h^2}(4\log\frac{L}{C} + +0.87\,\frac{1-u}{1+u}\,\frac{a-b}{a+b} + 1.069)$
Edge	13.	$S_e = \frac{1+u}{3+u}\,\frac{P}{h^2}\left\{8.80\log\frac{L}{C} - \frac{4u}{\pi} - 0.29 + \frac{3}{\pi}\left[(1+u)\frac{a-b}{a+b} + 2(1-u)\frac{ab}{(a+b)^2} + 1.18(1+2u)\,\frac{b}{L}\right]\right\}$
		Maximum Deflection, in.
Interior	2.	$d_i = \frac{P}{8kL^2}$
Edge	4.	$d_e = 0.41\,(1+0.4u)\frac{P}{kL^2}$
Corner	6.	$d_c = (1.1 - 1.24\,\frac{r}{L})\,\frac{P}{kL^2}$
Interior	8.	$d_i = (1-Z)\,\frac{P}{8kL^2}$
Interior	12.	$d_i = \frac{P}{8kL^2}\left\{1 - \frac{0.183}{L^2}\left[(a^2+b^2)(\log\frac{L}{C} + 0.159) - 0.435ab\right]\right\}$
Edge	14.	$d_e = P\sqrt{\frac{2+1.2u}{Eh^3k}}\left[1-(0.76+0.4u)\,\frac{b}{L}\right]$

where $L^4 = \frac{Eh^3}{12(1-u^2)k}$; $C = \frac{a+b}{2}$; $k = \frac{P}{Ad}$; $B = \sqrt{1.6r^2+h^2} - 0.675h$

P= Total load,lb; h= thickness,in.; u= Poisson's ratio;
r= Equivalent radius of plate with semi-axes a and b;in.;
E= Elastic modulus of concrete, psi; Z= a deflection ratio;
L_1= a multiple of L; and A= Area of soil supporting load.

been proposed by Pickett,[6] Hogg,[20] Holl,[21] Burmister,[22] Fox,[23] and Hank and Scrivner.[24] These investigators assumed that the pavement structure was a multilayered, elastic solid. Their equations, which are complex and which include soil "constants" not readily measured, are not considered in this study.

Comparisons of maximum strains and deflections of the five test panels with theoretical values computed using Westergaard's equations (or modifications) are presented in Figs. 11, 12, 13, and 14. Lines representing Eqs. 11 and 12 were not drawn on Fig. 11 because, for the loadings being considered, these equations provide data essentially the same as do Eqs. 1 and 2.

Constants for the theoretical computations of strains and deflections were: h = 6 in., a = 5.8 in., b = 3.5 in., r = 4.72 in. (radius of a circle with area equal to that of the ellipse with semi-axes a and b), u = 0.15, and E = 6,000,000 psi. The elastic modulus selected was the interpolated value representing an average E for the concrete during the slab testing period which was between the ages of 30 and 60 days.

Conversion of Computed Stresses to Strain

The equations of Table 10 yield stresses which were converted to strains in order to make the comparisons shown in Figs. 11 to 14. This conversion was accomplished as follows:

At interior locations the strains in the two principal directions were found to be about equal. Then, from the stress-strain relationship

$$S_i = \frac{E}{1-u^2}\,(e_x + u e_y)$$

with $e_{max} = e_x = e_y$ it may be shown that

$$e_{max} = (1-u)\,\frac{S_i}{E}$$

At the edges it is assumed that stresses normal to the edge may be neglected, and the strain is the ratio of S_e to E. Along the corner diagonals the strain orthogonal to the maximum strain has been found[16] to be approximately half the maximum strain but opposite in sign. The approximate maximum strain at the corner is then

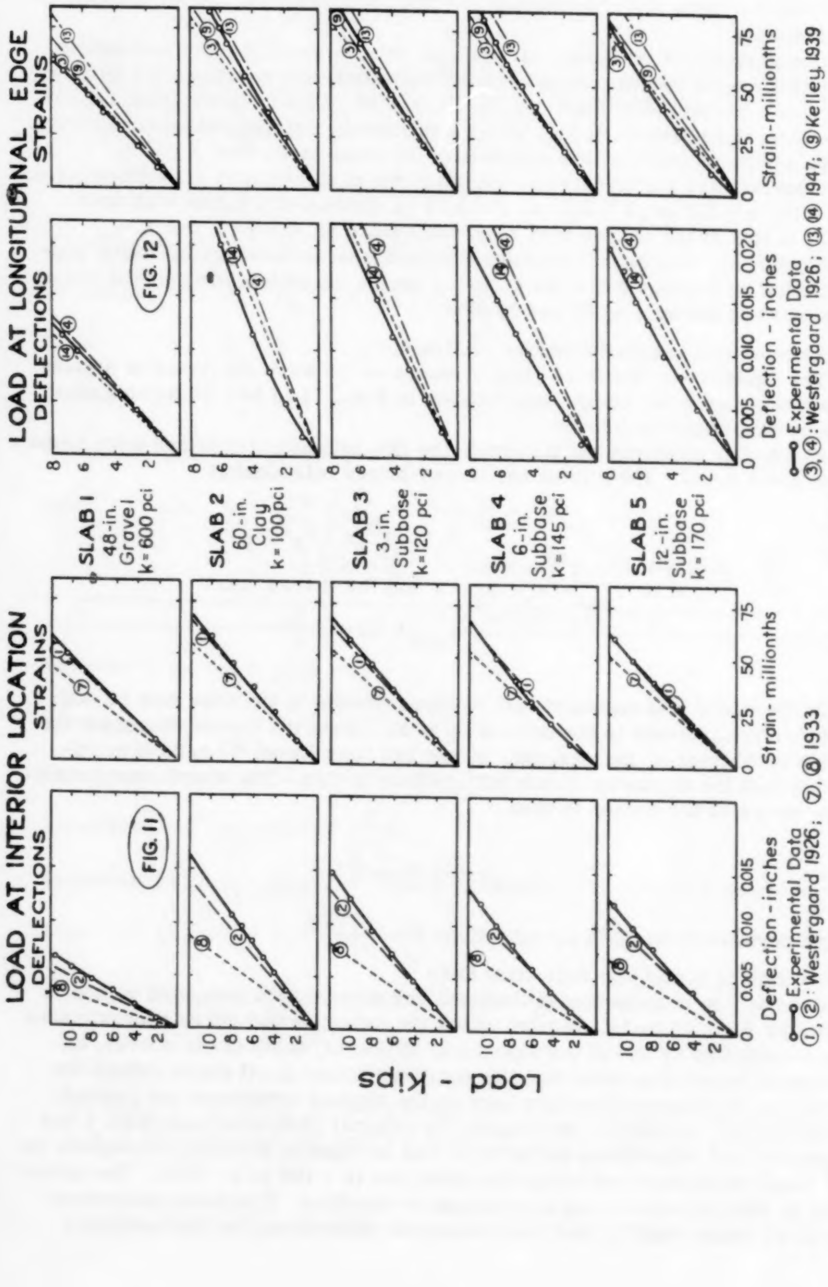
$$e_{max} = \frac{2(1-u^2)}{2-u}\,\frac{S_c}{E}$$

which deviates from S_c/E by only about 6%.

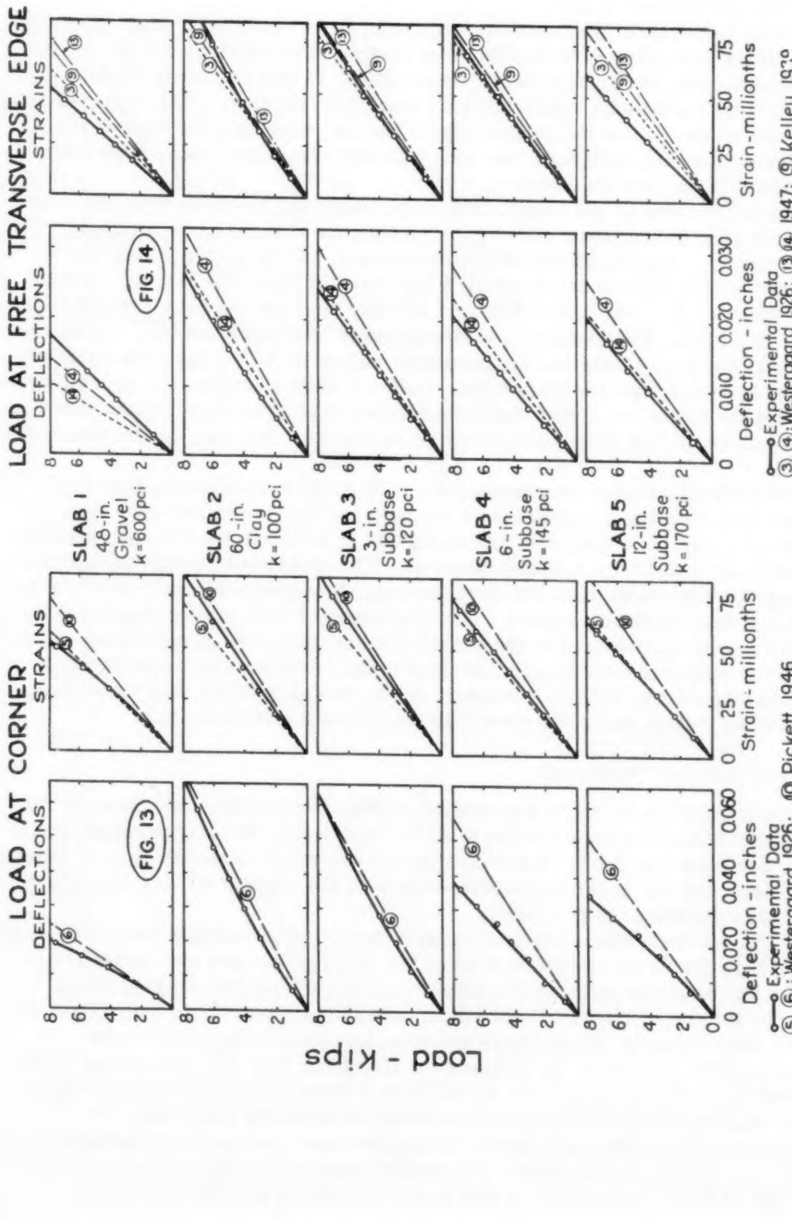
Discussion of Strain and Deflection Data

Comparison of measured deflections and strains with computed values is shown by Figs. 11 to 14. In most cases the experimental curve approximates a line computed by one of the equations. However, study of the curves, as discussed below, discloses that the equations do not in all cases reflect the variations in measured performance as the support conditions are altered.

INTERIOR LOADING. Westergaard's original 1926 equations (Eqs. 1 and 2) predict both deflections and strains with acceptable accuracy throughout the full range of subbase and subgrade conditions (k = 100 to k = 600). The agreement in measured and computed strains is excellent. Computed deflections are in all cases slightly less than measured deflections, but the measured



MAXIMUM DEFLECTIONS AND STRAINS



MAXIMUM DEFLECTIONS AND STRAINS

effect of varying the foundation is accurately represented by the equations. Westergaard's 1933 strain equation (Eq. 7) with Z = 0.39 and L_1 = 5L gives results which are less than the measured strains in all cases; and the associated deflection equation (Eq. 8) yields theoretical deflections which are also less than measured values.

EDGE LOADING. The equations considered here for edge loading are derived for a slab of infinite length. The measured deflections for the 15-ft. longitudinal and 10-ft. transverse edges (Figs. 12 and 14) agree closely except for the condition k = 600. At this value the deflection of the shorter edge is greater than that of the longer edge. The two edge lengths showed equal strains on the clay subgrade, but as k was increased the longer edge showed greater strains than the shorter.

The deflections at the longitudinal edge computed by Westergaard's 1926 equation (Eq. 4) are in all cases greater than the measured deflections. The 1947 equation (Eq. 14) shows better agreement, giving values which are slightly greater than those measured for the clay subgrade and for all subbase sections (k = 100 to k = 170) and slightly less for the deep granular subgrade (k = 600). For strains, the Westergaard 1947 equation (Eq. 13) agrees well with the measurements for the lower values of k, but his 1926 equation (Eq. 3) agrees better for higher k's. Kelley's 1933 equation (Eq. 9), falling between the other two, represents the average condition well, but all three of the strain equations show less response to changes in k than do the measured strains.

CORNER LOADING. Westergaard's 1926 deflection equation (Eq. 6) agrees well with the measurements for both the lower and the very high values of k, but the measured values are about 30% less for the intermediate k's for 6-in. and 12-in. subbase sections. The measured strains for corner loading, as was shown also for edge loading, show greater response to variations in k than do the equations. The Westergaard 1926 strain equation (Eq. 5) shows good agreement for the higher k's but otherwise gives values which are lower than those measured. Pickett's Eq. 10 which was developed for slabs having partial subgrade support, gives values greater than those measured in all cases, and shows too little response to variation in k.

Effect of Subbase Thickness

Data from Figs. 11 to 14 are plotted in Fig. 15 to show more directly the effect of subbase thickness at the 6000 lb. load level. Some significant indications are shown in Table 11 and are discussed below, although it is of course recognized that for other materials, even with the same k values, the effect of subbase thickness might differ.

(a) Corner deflections are particularly sensitive to subbase thickness up to about 12 in. (or to variations in k from 100 to 170), but are less sensitive to further increases in subbase thickness or in k. Within the range of these tests the measured effect of subbase thickness from 0 to 12 in. on pavement corner deflections is significantly greater than the effect computed by Westergaard's equations, as is apparent also from Fig. 13. According to the original Westergaard equations a change in k from 100 to 170 should reduce corner deflections by 26%; Fig. 15 shows a reduction of about 50%.

(b) Edge deflections and interior deflections are reduced approximately 55% by increasing the thickness of granular material to 48 in. (increasing k from 100 to 600). About half of this beneficial effect is achieved with a

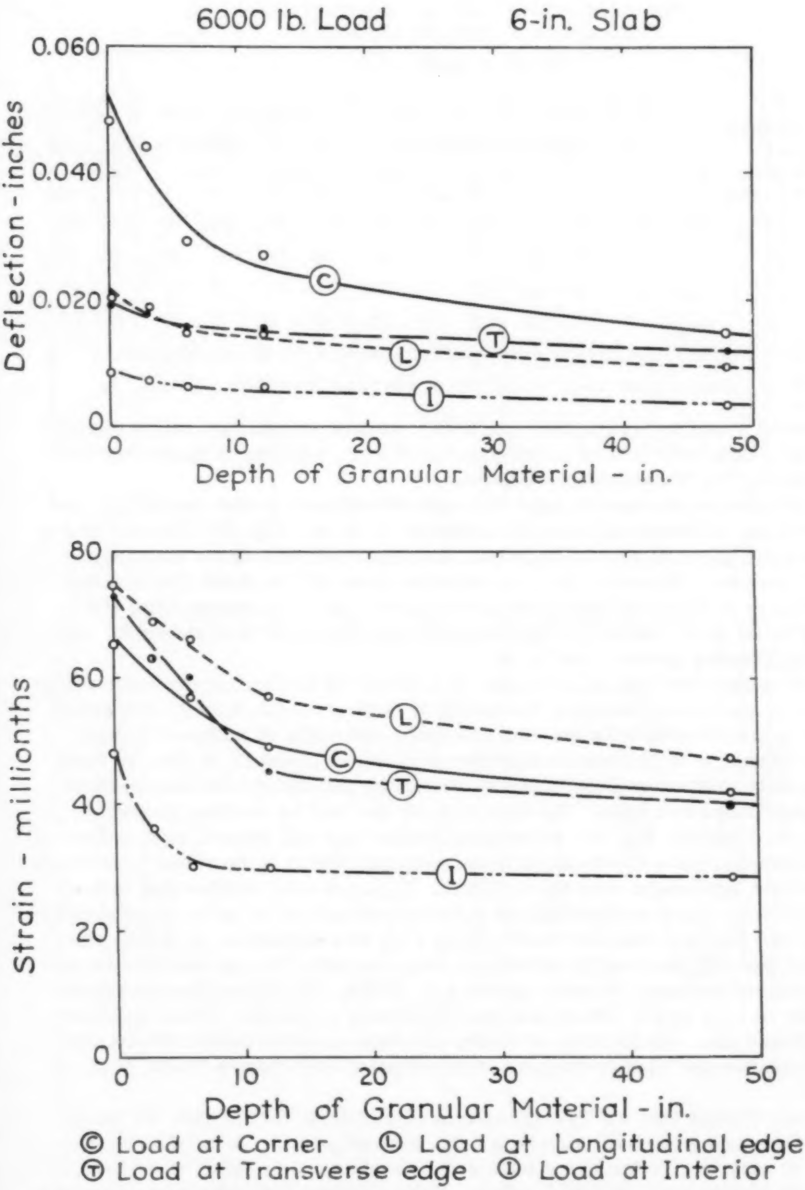


FIG. 15 - INFLUENCE OF DEPTH OF GRANULAR MATERIAL ON PANEL DEFLECTIONS AND STRAINS

Table 11

PER CENT REDUCTION IN DEFLECTIONS
AND STRAINS DUE TO SUBBASES

(Load = 6000 lb)

Thickness of granular mat'l, in.	k pci	Reduction in per cent of value on clay (k=100)											
		Deflection						Strain					
		Edge		Cor.		Int.		Edge		Cor.		Int.	
		W	X	W	X	W	X	W	X	W	X	W	X
48	600	59	56	64	71	59	57	20	37	19	37	17	20
12	170	24	33	26	52	24	30	6	25	5	26	5	19
6	145	17	27	18	38	17	27	4	13	3	17	4	17
3	120	9	14	10	25	8	15	2	8	2	9	2	11

W = Values computed from Westergaard's 1926 equations.

X = Values computed from experimental results, Fig. 15.

subbase of 6 in. (k = 145); little additional benefit is obtained with a subbase of 12 in. This reduction in deflection with a 6-in. subbase is more than that indicated by the Westergaard equations.

(c) Maximum strains for edge and corner loading are reduced 37% by increasing the thickness of granular material to 48 in. Fig. 15 indicates that a subbase thickness of about 8 in. would develop about half of the maximum benefit possible. In terms of k, an increase from 100 to about 150 was half as effective in reducing edge and corner strains as an increase from 100 to 600. For interior loading no significant strain reduction was shown for subbase thicknesses greater than 6 in.

Since deflections and strains may be reduced by thickening the concrete as well as by increasing subbase thickness, it is of economic importance to establish a relationship between slab thickness and depth of subbase to meet certain strain or deflection requirements. Curves II and IV of Fig. 16 show these relationships for 6-in. slabs supported by the materials used in these tests and loaded to 6 kips. The curves were derived as outlined below:

Curves I and III, Fig. 16, expressing deflections and strains as functions of slab thickness, were constructed from equations which were shown previously to give best agreement with the test data. Experimental strains and deflections for 6-in. slabs as functions of sub-base thickness (or of k) were shown in Fig. 15. For any subbase thickness in Fig. 15 a deflection or strain was selected (and adjusted by the difference between experimental and theoretical values for no subbase) to enter curves I or III Fig. 16, to find the thicknesses of a slab on clay at k = 100 to give that deflection or strain. These relationships (based on a combination of theory and experimental data) between subbase thickness and slab thickness furnished points for curves II and IV of Fig. 16.

Curves II show that a 7 1/2-in. slab is required on clay to give the same edge deflections as a 6-in. slab on a 6-in. subbase, and an 8-in. slab is required on clay to give the same edge deflections as a 6-in. slab on a 12-in. subbase. At a free corner an 8 1/2-in. slab is required to control deflections to equal those of a 6-in. slab on a 6-in. subbase, and a 10-in. slab is required to control deflections to equal those of a 6-in. slab on a 12-in. subbase.

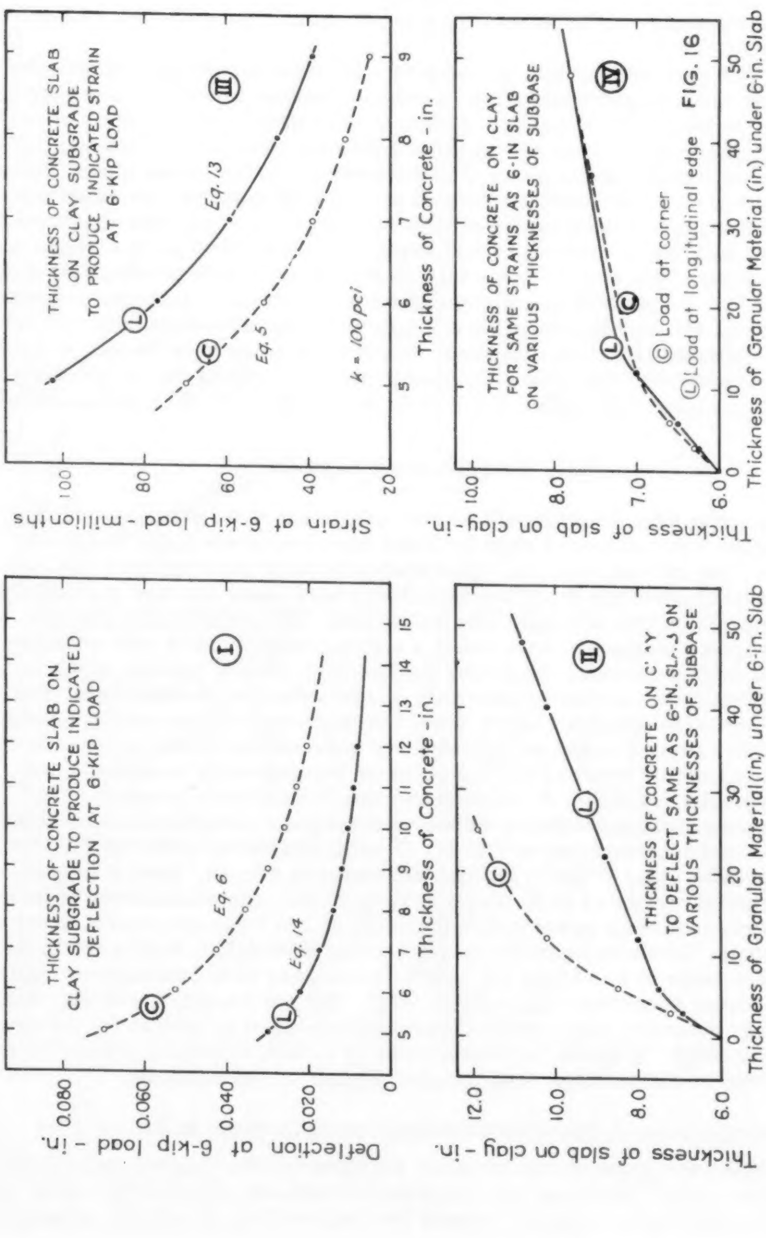

THICKNESS OF CONCRETE SLAB ON CLAY SUBGRADE TO PRODUCE INDICATED DEFLECTION AT 6-KIP LOAD
Eq. 6
Eq. 14
I
Deflection at 6-kip load - in.
Thickness of Concrete - in.
THICKNESS OF CONCRETE SLAB ON CLAY SUBGRADE TO PRODUCE INDICATED STRAIN AT 6-KIP LOAD
Eq. 13
Eq. 5
k = 100 pci
III
Strain at 6-kip load - millionths
Thickness of Concrete - in.
THICKNESS OF CONCRETE ON CLAY TO DEFLECT SAME AS 6-IN. SLAB ON VARIOUS THICKNESSES OF SUBBASE
II
Thickness of slab on clay - in.
Thickness of Granular Material (in.) under 6-in. Slab
THICKNESS OF CONCRETE ON CLAY FOR SAME STRAINS AS 6-IN SLAB ON VARIOUS THICKNESSES OF SUBBASE
IV
C Load at corner
L Load at longitudinal edge
FIG. 16
Thickness of slab on clay - in.
Thickness of Granular Material (in.) under 6-in. Slab

Fig. 16.

Curves IV show that equivalent stresses at both the corner and the edge can be controlled with less thickness of concrete than is required for equivalent deflections. For instance, a 6 1/2-in. slab on clay gives the same strains as a 6-in. slab on a 6-in. subbase. Similarly a 7-in. slab on clay holds the strains to the same values as a 6-in. slab supported by a 12-in. subbase.

These data showing that the dense-graded subbase was much more effective in reducing deflections than in reducing strains are of particular significance in the design of concrete pavements on plastic subgrade soils susceptible to pumping. If these data represent average subbase performance, it is apparent that one of the primary functions of a subbase is that of reducing deflections, with accompanying reduced tendency for pumping. Subbases also are effective in increasing the strength of the pavement by reducing strains due to load, but in most cases this might be accomplished more economically by thickening the slab. For the materials covered by this investigation it appears that a 6-in. subbase, which experience indicates is sufficient to prevent pumping, will be effective in significantly reducing deflections, and will result in a moderate reduction in strains. However, in these tests the use of a subbase thicker than that commonly used to prevent pumping did not add greatly to the load-carrying ability of the pavement and thus might be uneconomical.

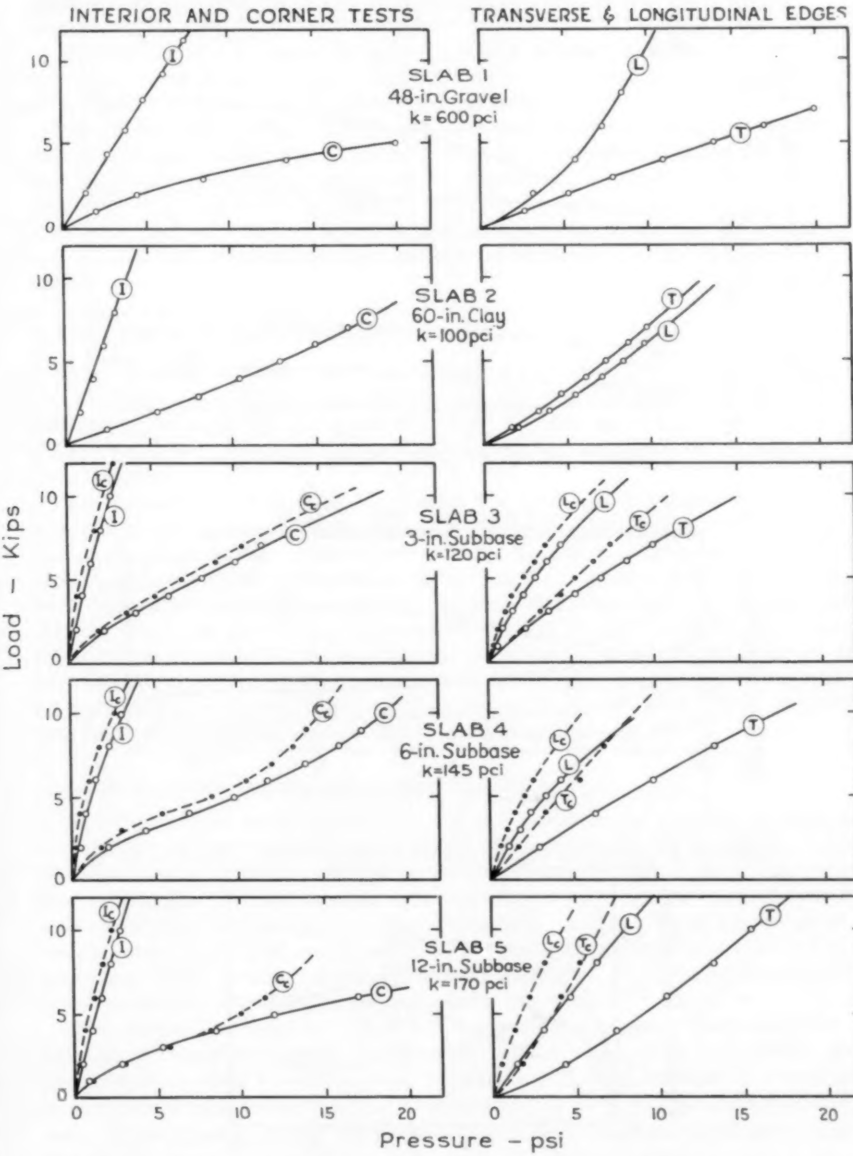
Load-Pressure Relations

Reactive pressures beneath the test panels and at the subgrade-subbase interface were measured when the slabs were loaded statically at corners, edges, and interior locations. Maximum pressures directly under the load and data on pressure distribution at other points under the slab were obtained in conjunction with accompanying deflections. The pressure cell used for measuring pressures is essentially a stress meter(7) and is very sensitive to small axial movement. Its proper function is dependent upon the uniform distribution of material intimately in contact with the cell diaphragm. Particle intrusion into this critical area, soil shrinkage, or pavement panel curl will alter the cell response and introduce uncertainties in the results. In most cases it is believed that the pressure readings were reasonable, but occasionally, as in Slab 2, the response was thought to be in error.

Curves showing maximum subbase and subgrade pressure as a function of wheel load are presented in Fig. 17. Pressures directly under the 6,000-lb. loads which apply 86 psi to the slab are shown in Fig. 18. Here it is seen that the highest pressures in the range of 10 to 20 psi or more occurred at free corners, and lowest pressures in the range of 2 to 4 psi occurred at interior locations. Pressures under free longitudinal edges (15 ft. long) were in the general range of 5 to 10 psi for a 6000-lb load, and were less than one-half those under transverse edges (10 ft. long). The one exception was Slab 2 on the clay subgrade, which showed approximately equal pressures for the two edge loadings. It should be remembered, of course, that these pressures are for isolated slabs without load transfer devices or end restraint.

Effect of Subbase in Reducing Pressures on the Subgrade Soil

The second graph of Fig. 18 shows pressures on the clay subgrade under 6,000-lb. loads. It is seen that the granular subbases significantly reduce the pressures. This is most pronounced for the first 6 in. of subbase, although



MAXIMUM PRESSURES BENEATH SLAB AND SUBBASE

I, C, L & T Pressures directly beneath slab at interior, corner, long. edge and trans. edge
I_c, C_c, L_c & T_c Pressures on clay, beneath subbase

FIG. 17

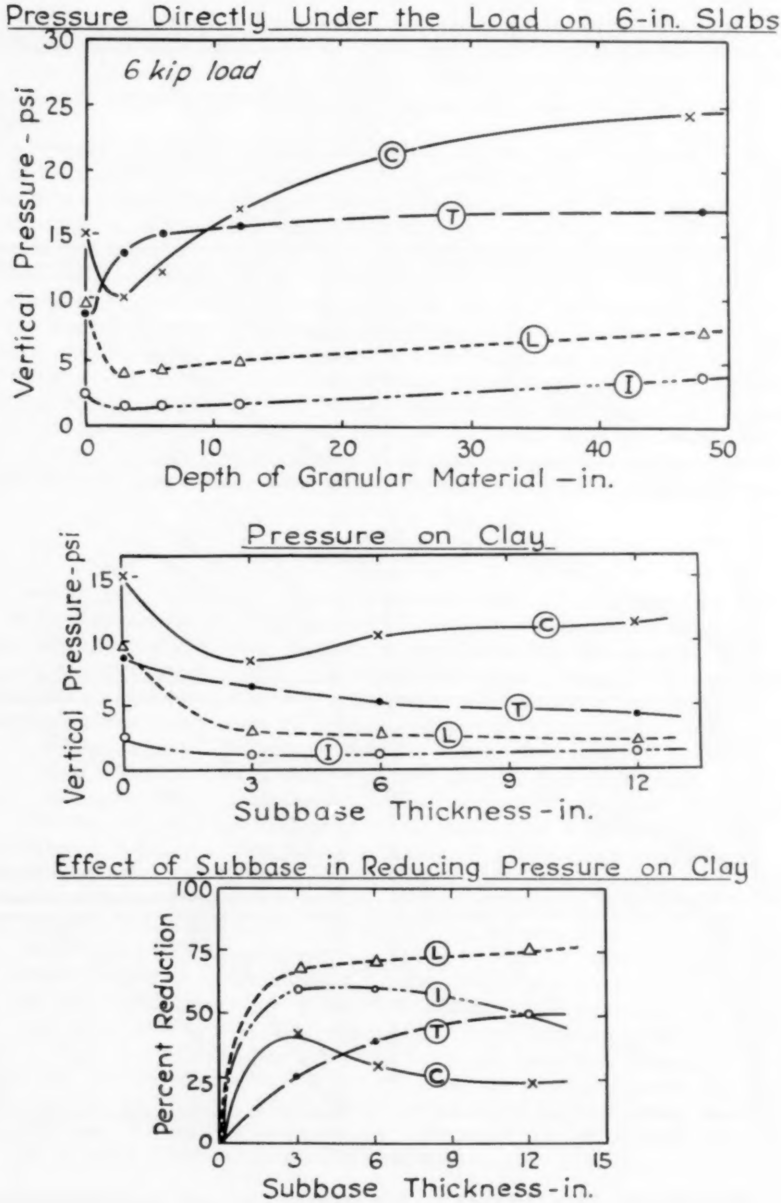


FIG. 18 - PRESSURES UNDER SLABS

Ⓒ Ⓣ Ⓛ & Ⓘ indicate corner, transverse edge, longitudinal edge and interior loads respectively.

the pressures continue to decrease with further increase in subbase thickness. An unexplained variation in this trend is seen at the free corner location.

This ability of a granular subbase to reduce pressures transmitted to the subgrade and to greatly reduce slab deflections undoubtedly contributes to the performance of a subbase in preventing pumping.

The third graph of Fig. 18 shows the pressure-reduction data expressed on a percentage basis. The effect of subbases on pressures at the interior and the longitudinal edge is particularly significant, showing reductions of about 50% to 70% for a 3-in. subbase, with only minor changes as the thickness is increased. The corner data are inconsistent, showing a 40% reduction for the 3-in. subbase and somewhat less reduction for the thicker subbases.

Distribution of Pressures along Slab Center Line

Since pressures at the interface between a concrete slab and the subbase are not large compared to the applied load, the reactive pressures must be distributed over a large area. As shown in Fig. 8 pressure cells were installed along the slab center-lines to ascertain the nature of the pressure distribution.

Fig. 19 shows that an 8000-lb. load on the 6-in. slab produces reactive pressures over a considerable distance. When the load was applied at the end of the panel, at the center of the transverse edge, in three of the five slabs pressures were indicated on the cell at the center, which was 7 1/2 ft. from the load. Loads 5 ft. from the end produced measurable pressures on the end cell in all five slabs, but loads at the slab center caused measurable pressure at the slab end in only Slab 3. Thus an 8-kip load at the interior of a 6-in. slab caused reactive pressures of measurable magnitude throughout an area having a diameter greater than the width of the panel. This area of influence is approximately 60% of the total area of the panel.

Relation Between Reactive Pressure and Deflection

The theoretical equations of Table 10 are based on the assumption that the ratio of pressure to deflection is constant everywhere under a concrete slab. Observations of pressure-deflection relationships during the study confirmed this assumption as a reasonable approximation except for the case of Slab 2 which was placed directly on the clay subgrade. In Fig. 20 the curves show the pressure-deflection relationship in the immediate vicinity of the load for all slabs. When measuring facilities were available, these same trends were corroborated at points some distance from the load.

The curves for slabs 1, 3, 4, and 5 are closely grouped. They show that the assumption of a constant pressure-deflection ratio for these slabs is not unreasonable. Slab 2 shows a wide spread, and it is impossible at this time to say whether the fault lies in the assumption or in some peculiarity of the test. Lines approximating the pressure-deflection ratio for each slab (except Slab 2) are drawn at the bottom of Fig. 20. These lines indicate ratios (or k values) that are 50 to 100% greater than those measured by the plate bearing tests as indicated in the following tabulation:

	Slab 1	Slab 3	Slab 4	Slab 5
k from plate	600	120	145	170
p/d from slab	920	200	290	335

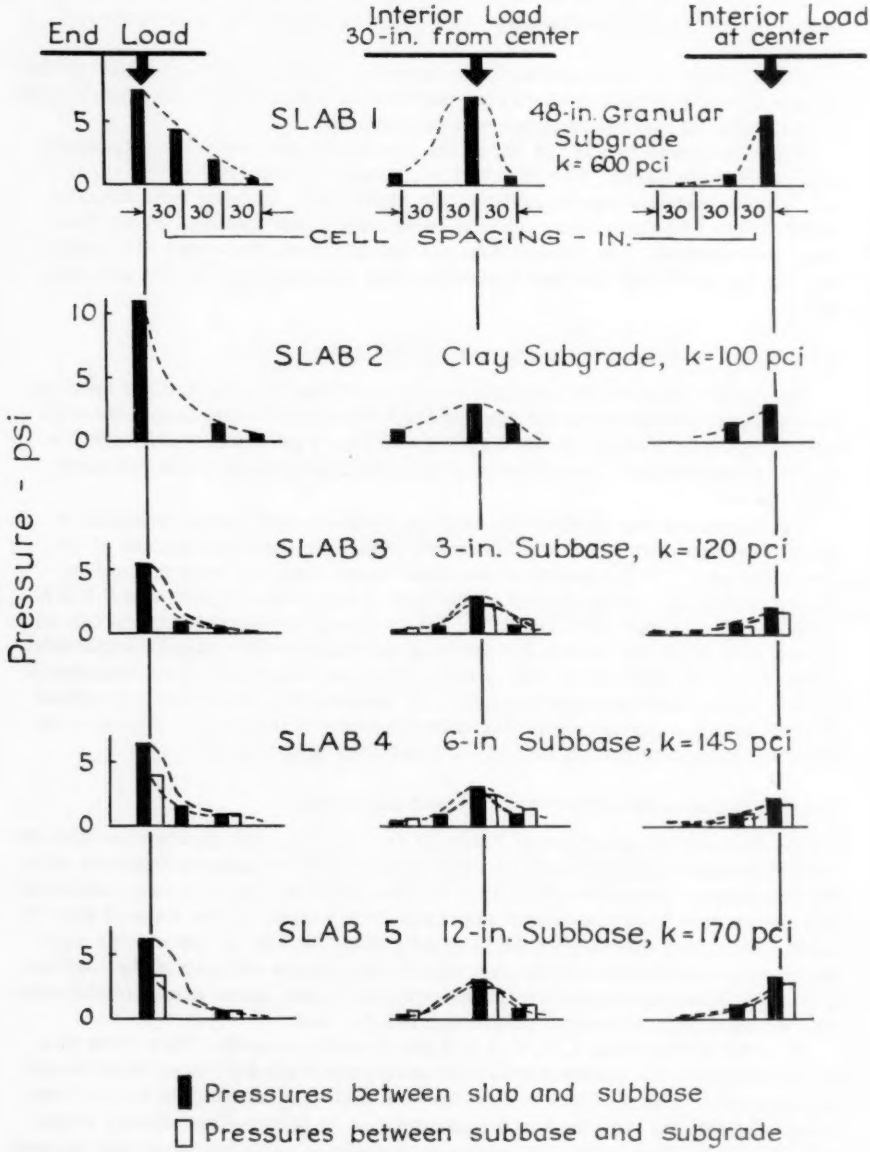
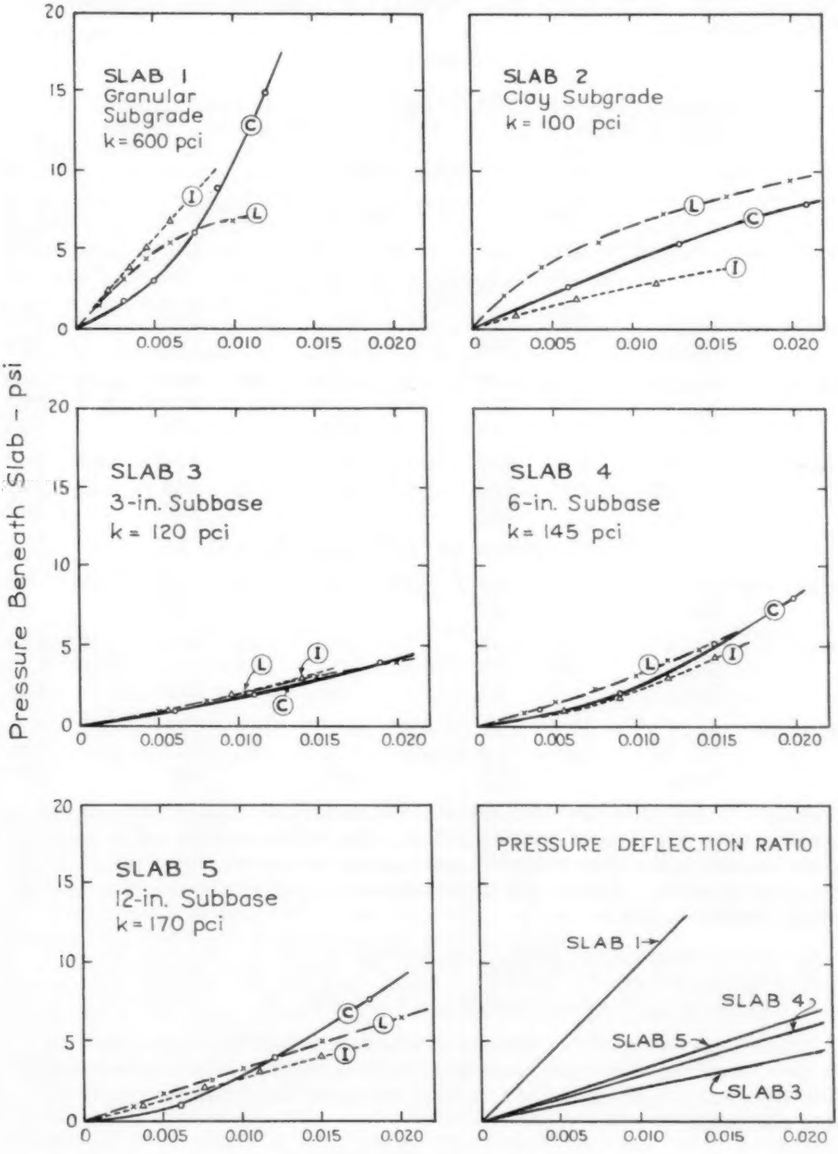


FIG. 19 - DISTRIBUTION OF REACTIVE PRESSURES ALONG CENTER LINE OF SLAB

8 Kip Load



PRESSURE DEFLECTION RELATIONS AT POINT OF LOADING

(C) Load at corner (L) Load at longitudinal edge (I) Load at interior

FIG. 20

A recomputation of stresses and deflections using p/d from the above tabulation was made, and in Table 12 the results are compared with those using k from plate tests.

Table 12

COMPARISON OF SLAB STRESSES AND DEFLECTIONS USING k FROM SLAB TESTS AND FROM 30-in. PLATE

(6-kip load)

		Slab 1		Slab 3		Slab 4		Slab 5	
Position	k(pci)=	920	600	200	120	290	145	335	170
		Maximum Stress, psi							
Interior	Eq.1	188	198	223	234	214	230	211	227
	Exp.		198		240		205		212
Edge	Eq.3	272	290	335	257	320	349	314	343
	Eq.9	299	318	363	385	347	378	342	371
	Exp.		282		415		402		343
Corner	Eq.5	230	247	285	301	273	295	268	290
	Eq.10	295	318	372	394	355	385	347	379
	Exp.		245		355		320		280
		Maximum Deflection, 0.0001 in.							
Interior	Eq.2	23	29	50	66	42	59	39	55
	Exp.		33		72		60		59
Edge	Eq.4	82	101	175	226	145	205	135	189
	Eq.14	69	87	155	204	128	184	118	169
	Exp.		95		184		143		145
Corner	Eq.6	148	191	357	475	289	429	267	391
	Eq.15	136	168	290	371	240	343	226	315
	Exp.		160		450		290		270

A study of Table 12 shows that stresses and deflections computed from theory are less when p/d is used instead of k, but this reduction does not in general cause the new theoretical value to approximate the experimental values more closely than before. Significant improvement is obtained, however, in the following specific cases:

1. Corner stresses for Slabs 3 and 4 using Eq. 10
2. Edge deflections for Slabs 3, 4, and 5 using Eq. 4.
3. Corner deflections for Slabs 4 and 5 using Eq. 6.

It may be concluded that the use of k as determined from plate tests in the theoretical equations produces stress and deflection values in reasonably close agreement with experiment in this test more often than the use of p/d from slab tests.

Computation of Pressures from Deflections

Once the p/d ratio has been established for a pavement slab by a limited number of pressure and deflection measurements, the pressures beneath a slab at any point can be approximated by multiplying the deflection at that point by the ratio p/d. Since deflections are measured very easily, this relationship is of considerable value in the study of pressure distribution.

This method is illustrated in the Appendix for the case of corner pressures along the bisector of Slab 3. A verification of the validity of the method is included.

Loads to Failure

For a final evaluation of the contribution of subbases to the structural strength of a roadway, the concrete slabs were loaded to failure. These failure loads were applied with the panels in a flat condition, that is, with no appreciable curl. A corner was broken first and then the longitudinal edge on the opposite side was loaded to failure. Occasionally after these breaks a slab had sufficient integrity to justify a second corner break. No failure loads were attempted at interior positions.

The data from failure tests are given in Fig. 21. It is seen here and in Table 13 that ultimate load increases with increase in subbase thickness for both edge and corner locations, and the failure load at the edge is slightly greater than that at the corner.

Table 13

LOADS, STRAINS, AND DEFLECTIONS AT FAILURE

		Corner Region			Longitudinal Edge		
Slab	k pci	Load, kips	Strain 10^{-6}	Defl'n in.	Load kips	Strain 10^{-6}	Defl'n in.
1	600	21.5	240	0.165	22.0	240	0.090
2	100	14.0	170	0.150	16.0	200	0.070
3	120	15.0	160	0.170	18.0	190	0.055
4	145	16.0	190	0.120	18.5	240	0.070
5	170	18.0	190	0.105	20.5	230	0.080

The corner-to-edge strain ratio of 88% which was developed in Table 8 does not hold in the data of Fig. 21. In Slab 1 the corner strains exceeded the edge strains for the entire load range but converged at failure. The load-strain curves for edge and corner loads were close together for Slabs 2, 3, and 5 until the load approached that producing corner failure. In Slab 4, edge strains exceeded corner strains in the middle load range.

At the "working load" levels the strains and deflections shown by Fig. 21 are in some cases greater than those shown by Fig. 10. This is undoubtedly due to small but unavoidable curling which developed prior to the failure tests. However, it is believed this minor curling had little influence on the failure loads. Further studies of curled slabs are planned.

Flexure tests on control beams gave modulus of rupture values at age 10 weeks approximating 800 psi. At E = 6,000,000 psi, an average strain at failure should be about 130 millionths. The strains shown in Table 13 exceed this value. It is apparent that conventional elastic analysis is not applicable for computing the ultimate tensile strans in pavement slabs.

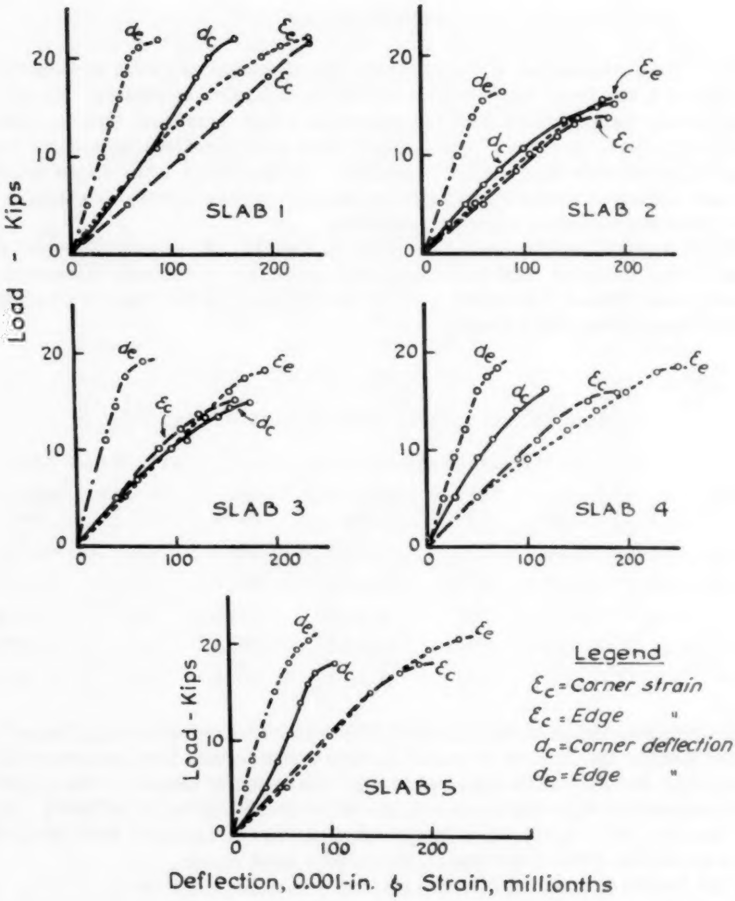


FIG. 21 - LOAD TESTS TO FAILURE

CONCLUSIONS

Static load tests were made on isolated rectangular uncurled concrete panels 6 in. thick supported by dense-graded, well compacted granular subbases of different thicknesses over a clay subgrade with a k of 100. The conclusions from the study, listed below, apply to the materials and conditions described in this report. Extrapolation of the data to other materials and conditions is not considered justified until confirming data become available.

1. Slab deflections and stresses due to static load decreased as the subbase thickness was increased (Fig. 15). Failure loads increased as the subbase thickness increased (Table 13). The economic relationship between subbase depth and thickness of concrete slab may be estimated by the trend in these tests. An analysis based on measured load-strain and load-deflection relations and on close-fitting theoretical curves (Figs. 15 and 16) shows that:

a. The stresses induced at the edge and at a free corner in a 6-in. slab on a 6-in. well compacted, dense-graded subbase were the same as would be expected in a 6 1/2-in. slab with no subbase; and the stresses in a 6-in. slab on a 12-in. subbase were the same as would be expected in a 7-in. slab with no subbase.

b. The deflections at the edge of a 6-in. slab on a 6-in. subbase were the same as would be expected with a 7 1/2-in. slab with no subbase; and the deflections of a 6-in. slab on a 12-in. subbase were the same as would be expected with an 8-in. slab with no subbase.

c. The deflections at a free corner of a 6-in. slab on a 6-in. subbase were the same as would be expected with an 8 1/2-in. slab with no subbase; and the deflections of a 6-in. slab on a 12-in. subbase were the same as would be expected with a 10-in. slab with no subbase.

Thus, on low bearing value subgrades, it appears that strains may be reduced effectively and economically by small increases in slab thickness, and that deflections may be reduced substantially by the use of a dense-graded, well compacted subbase. The greatest effectiveness per inch of subbase in the reduction of deflections is obtained with subbases about 6 in. thick. Since experience indicates that subbases of this thickness, or even less, will prevent pumping, the use of subbases of greater thickness may not be structurally economical.

2. Pressures directly beneath the load at the slab-subbase interface increased as the thickness of granular material was increased (Fig. 18). At a load of 6000 lb. the pressures at the interior ranged from approximately 2 to 4 psi; those at the longitudinal edge, 4 to 8 psi; and those at an isolated corner, 10 to 25 psi.

3. Pressures at the subbase-subgrade interface decreased with increases in subbase thickness, and they were less by approximately 25 to 75% than those beneath the slab when the slab was built directly upon the clay (Fig. 18).

4. The current equations for calculating deflections and strains provided reasonable agreement with measured values (Figs. 11, 12, 13, 14), with the qualitifications indicated below:

a. For deflections and strains at the interior, Westergaard's 1926 formulas gave computed values reasonably close to actual test results.

b. For deflections at the longitudinal edge, Westergaard's 1947 equation provided the best check. For strains at the edge, Westergaard's 1947 equation (Eq. 13) agreed well with measurements for the lower k values but his 1926 equation (Eq. 3) agreed better for higher k's. Eq. 9 is a compromise representing an average condition. For foundations including subbases with k value from 120 to 170, none of the theoretical equations were as responsive to changes in k as were measured strains and deflections.

c. When the load was at the corner the measured deflections at both high and low k values agreed with Westergaard's 1926 equation (Eq. 6). At intermediate k's the measured values were less than computed values by about 30%. In this area, the Westergaard equation is less responsive to changes in k than are the measured deflections. Measured strains were approximated by Eq. 5 for higher k's but were greater than values computed by this equation when k was low. Pickett's equation (Eq. 10) gave strains consistently higher than those measured.

5. For flat slabs, pavement thickness design equations involving the subgrade reaction modulus k proved to be reasonably applicable to both the single subgrade and the layered system when k was computed from 30-in. plate tests on the top surface of the composite system. However, as already discussed, the theoretical equations in many cases were not as responsive to changes in subgrade support as were the measured values. The extent to which these formulas or their modifications agree with experimental results on curled panels must be fully ascertained by tests on slabs subjected to load cycling and restraints typifying highway conditions.

APPENDIX

Computation of Pressures from Deflections

An approximation of the reliability of pressure measurements may be obtained by using the constant pressure-deflection relationship shown in Fig. 20 and the deflections along the bisector of a corner. These data may be used to construct a curve representing the distribution of pressure along the bisector. By integration and revolution of sectors of this curve through a 90 degree arc, the total reactive force of the subgrade can be determined. A favorable comparison of the reactive force with the applied load may be taken as an indication that the pressure cells are measuring pressures of the proper order of magnitude.

This analysis may be extended to check deflections by dividing the pressure distribution curve into segments and finding the reactive force for each segment. Then, by assuming that a section of the pavement along the bisector behaves as a cantilever beam, it is possible to compute theoretical deflections along the bisector. The cantilever is assumed fixed at the corner and loaded at the point of zero deflection with the applied load. The reactive forces are placed along the beam as loads causing negative moments at the centroids of the various sectors of the pressure curve.

This analysis was performed on Slabs 1, 3, and 4, where deflection data were available. A detailed description of the procedures is shown for Slab 3 in Fig. 22. In this figure, load data were used to plot the two graphs, (A) deflection vs. distance from the load, and (B) pressure vs. deflection at the corner. To obtain pressure at any distance, enter graph (A) at the distance

and find the associated deflection. Then enter graph (B) with this deflection and read the pressure at a given distance. Use these data to plot curve C, a pressure-distance relationship for the corner bisector. Thus pressures may be found at any point.

Verification of the Method

The area under curve C, Fig. 22, is separated into convenient blocks. The blocks are rotated one-quarter turn about the pressure axis to find the reactive force on each concentric quarter-ring. The summation of these reactive forces is equal to 7252 lb., which is in good agreement with the applied load of 7240 lb.

An M/x diagram is constructed for the beam loaded as shown in D. Computations are illustrated below the diagram. To reduce the amount of computation, adjacent pairs of blocks are combined to form four areas, and numerical values of the areas are shown in Fig. 22. The centroids are also computed.

The deflection is the difference of the positive and negative moment areas divided by EI. The numerical calculations give the value 0.052 in. as the deflection at the corner. This compares favorably with the measured value of 0.056 in. shown in Graph (A), Fig. 22. Deflections at other points along the pressure-distribution line may be obtained in a similar manner.

Verification was established for Slab 4 by comparing a measured 0.040 in. deflection under 8900-lb. load with a computed deflection of 0.042 in. and a reactive force of 9150 lb.

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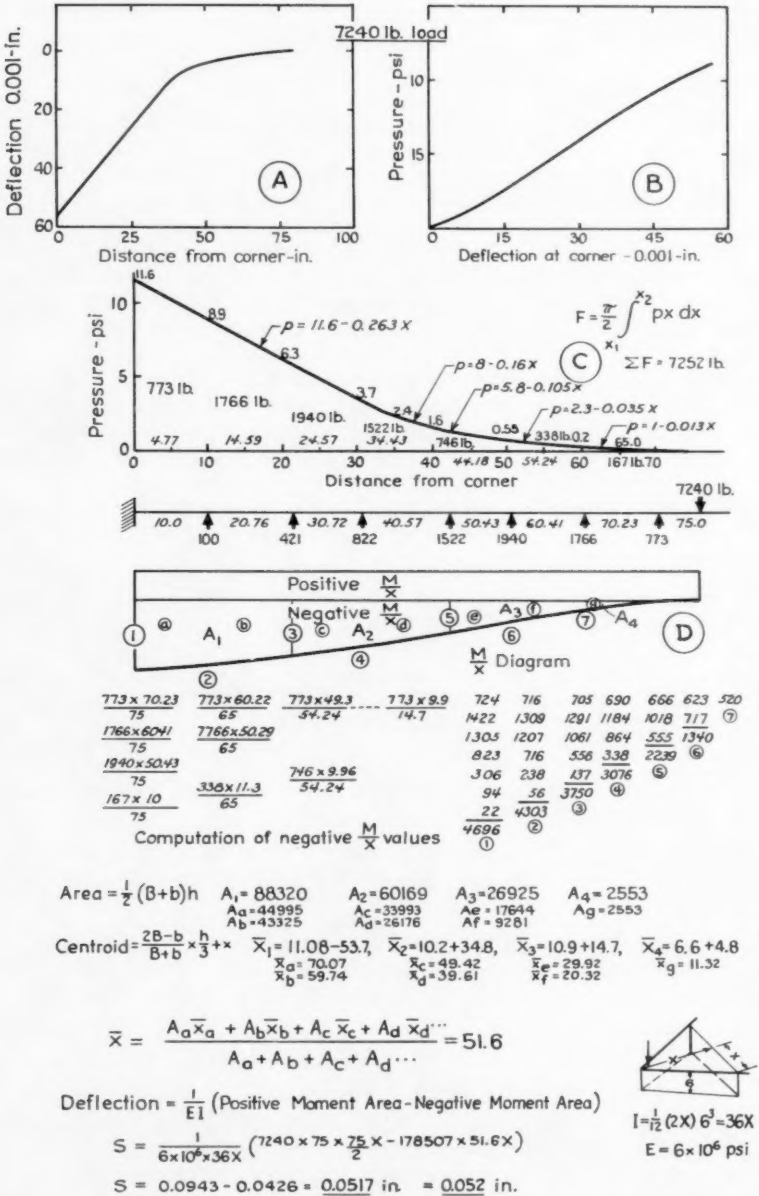

PRESSURES UNDER CORNER BISECTOR FOR SLAB 3

FIG. 22

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Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

HIGHWAY PLANNING PAST, PRESENT, AND FUTURE

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(Proc. Paper 1298)

SUMMARY

Highway planning on a comprehensive scale has been carried out jointly by the Bureau of Public Roads and the State highway departments throughout the past twenty years. Facts have been assembled and highway needs determined, greatly affecting State and Federal legislation. Methods must be perfected for keeping the needs studies current and projecting them into the future.

Highway planning on a national scale has emanated largely from several important Acts of Congress over a 40-year period. The signing of the 1956 Federal-aid Highway Act, which provides for our present ambitious program, was just 40 years after the signing of the Federal-aid Road Act of 1916, which marked the beginning of the State and Federal partnership in road building.

Selection of Federal-aid System

This partnership consists of the Federal Bureau of Public Roads and the highway department of each State. The first extensive joint planning undertaking was the selection of the Federal-aid system of highways provided for in the Federal-aid Highway Act of 1921. In the earlier years of road building, the automobile had been regarded as a pleasure vehicle rather than as an important means of transportation. Consequently, comparatively short sections of roads were built out from cities into the country with little regard

Note: Discussion open until December 1, 1957. Paper 1298 is part of the copyrighted Journal of the Highway Division of the American Society of Civil Engineers, Vol. 83, No. HW 3, July, 1957.

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to transportation needs. As the automobile was improved and ownership became more widespread, the idea of a highway transportation network began to take root.

The laying out of the Federal-aid system which was limited by law to 7 percent of the rural road mileage existing in each State, was not very difficult. It consisted mainly of the selection of routes which would connect all important population centers, disregarding State lines.

The idea of a continuous, nationwide system of roads was advanced still further by the adoption, in 1925, of a United States numbered system composed of important through routes extending entirely across the nation at frequent intervals. It was not an administrative system, but simply a basis for route marking as a guide for motorists.

Closing the Gaps

With the adoption of a Federal-aid system and the marking of through routes, the demand of the public was to "close the gaps." With State highway-user tax and other funds, supplemented in some cases by bond issues, and Federal-aid funds, this task was largely completed by the early 1930's. It was possible, then, to travel from almost any point in the United States to almost any other point on smooth, all-weather roads except, possibly for a few miles at either end of the journey.

The problem facing roadbuilders during this period of completing the through routes was fairly definite and simple. The system on which funds were to be expended was laid out, and the work of constructing the system progressed as rapidly as funds became available. Considerable research was undertaken by the various States and by the Federal Government to aid in the establishment of specifications and standards of construction; however, road types and standards were governed by definite cost limitations to permit the construction of the greatest possible mileage in the shortest possible time.

Problems Arise

In the early 1930's we began to be faced with different and far more complex problems, due largely to the rapid change in the character of highway transportation. Increases in automobile ownership, traffic volumes, vehicle speeds, and in the number and weights of trucks were far greater than could be visualized by the engineers of the early road-building days. Or, if they were visualized, they could not be provided for because of the popular demand to use every available dollar to build all-weather surfaces on the through routes. Hence, our early highways were entirely inadequate for the increased service demanded of them; inadequate as to surface thickness, width, grade, and alinement.

To make matters worse, with the gaps in the important through routes largely closed, there was an increasing public demand to increase the State system mileage to include roads of lesser importance, to transfer portions of the State highway-user taxes to local agencies for the improvement of local roads, and even to divert portions to nonhighway purposes. Thus the highway departments were faced with increasing responsibilities without

correspondingly increased revenues. The public did not realize the extent of the modernization and replacement problem and there was need for the collection, analysis and publicizing of facts, if public support was to be gained for an adequate highway program.

There were several other important problems, the solution of which called for the collection and analysis of facts. One was the selection of the secondary or feeder roads on which Federal funds might be expended as provided for in the Federal-aid Highway Act of 1936 and subsequent acts. Another had to do with trucks which were rapidly increasing in numbers, in size, in weights transmitted to the pavement, and in range of operation. What changes in design were needed to accommodate these vehicles, what damage were they doing to the highways, what limitations should be imposed upon them, and how and in what amount should they be taxed? It became clear to those who had devoted much thought to highway matters that there was an urgent need for the collection and analysis of facts concerning highways and the vehicles that use them, on a much more comprehensive scale than had ever before been attempted.

Highway Planning Survey Initiated

Beginning with the Federal-aid Highway Act of 1934, Congress has provided that 1-1/2 percent of the amount of Federal-aid funds apportioned for any year to any State might be used for surveys, plans, engineering and economic investigations of projects for future construction. Starting in the autumn of 1935, the States, one by one, took advantage of this provision in the Federal law, and entered into an agreement with the Public Roads Administration relative to the conduct of a comprehensive highway planning survey. By 1940 all of the States had begun to participate and all are continuing to do so.

In the initiation of this cooperative undertaking Public Roads proposed the studies, developed the procedures, rendered technical assistance, and consolidated data for use in the study of national problems. The States have proposed additional studies where needed for State problems, set up work programs, made the field surveys and summarized and analyzed the results. The programs and reports have been subject to approval by the Bureau in the discharge of its responsibilities with respect to the expenditure of Federal funds.

Funds Available

The funds available under this program have been reasonably adequate for the needed investigations though not large in relation to the magnitude of the problem. In the 1936-1939 period, unemployment relief funds, which were still available for highway work, were sufficient to permit the initial collection of information on a comprehensive scale. In 1940, Federal 1-1/2-percent funds amounted to about $2,000,000 and State-matching funds made almost double this amount available. In 1955 the Federal funds amounted to about $8,000,000. Under the presently enlarged Federal program they will be much larger, but the State funds will be considerably less than the Federal

funds because of the 90:10 matching ratio for the Interstate system. Then, too, the need for information will be greater.

The studies made by the States in the cooperative program have been supplemented by research projects carried out by the Bureau with administrative funds. This research has resulted in improved procedures, better interpretation of survey results and improvements in design, greatly enhancing the usefulness of the data at both State and Federal levels. The States have applied the results of the studies to State problems and the Bureau has applied them to Federal problems, and to problems common to all, or many of the States.

The surveys have been conducted differently in some particulars in different States, but on the whole they have followed a practically uniform pattern which will be briefly described.

Road Inventory

Initially, a complete inventory was made of all rural roads which were publicly traveled to determine in detail what the road facilities were. Observers drove over every mile of road and recorded the width, type, and condition of all roadway surfaces; the type, dimensions, and condition of all structures, the location of all dwellings and other cultural features which are sources of traffic, and the physical characteristics of all railroad grade crossings. On the important routes they measured the location and degree of curvature of all sharp curves, the location and rate of all steep grades; and the location and nature of all restrictions to road visibility which might present a traffic hazard.

The inventory data were summarized in tables, and in addition a series of county maps was prepared in accordance with standards agreed upon by all States, which show all public roads and their surface type in relation to the adjacent dwellings and other improvements. State maps, showing the principal highways but not the cultural features, were also prepared. The maps constitute, in themselves, an extremely valuable tool for the use of the State highway organizations in their regular work, and in addition they supply information which is valuable to other State agencies, to Federal agencies, and to private agencies and individuals. They are generally sold at a price approximating their reproduction cost, and the demand for them has been large and continuous.

Most States have provided for periodic reinventory and the revision of county maps at varying intervals, usually about 5 years. State maps are generally revised annually.

Rural Traffic Survey

A traffic survey was made, consisting of several distinct phases, the two most important of which, initially, were the determination of the volumes of traffic by vehicles of different types on all rural roads and the obtaining of information concerning weights and dimensions.

In determining traffic volumes a sampling method was used. Automatic traffic recorder and control station counts were used to establish factors to translate short counts, which were taken over the entire road network, into

average daily traffic volumes. This procedure has been greatly refined over the years and is now placed on a firm statistical basis. Following the original survey, traffic trends have been determined by the operation of continuous-count machines at selected points and extensive traffic counts have been made periodically by sampling procedures. State traffic-flow maps have been prepared and generally revised annually, and county traffic maps at less frequent intervals.

Trucks were weighed and measured at a large number of stations located on important highways. The information obtained included the type and some measure of the capacity of the vehicle; the total weight and the load on each axle; the width, height, length and axle spacing; the commodity carried and, when possible, the weight of the carried load; the origin and the destination of the vehicle; and other pertinent facts.

The weight information has been kept current by trends established through annual weighings at selected points during comparable periods. In addition, most States have occasionally made more extensive weight surveys to determine variations in different hours and in different seasons, and on different classes of roads.

Financial and Motor-Vehicle-Use Studies

A group of financial studies was undertaken to determine the present relation of street and highway finances to the finances of all other governmental operations within each State, to determine the ability of the State to finance the necessary highway maintenance, replacements and improvements, and to indicate an equitable base for the assessment of highway-user taxes.

One was the road-use survey in which a representative sample of motor-vehicle owners were interviewed to determine their annual travel and the class of roads and streets used for that travel. The data obtained made it possible to determine the proportional amount of travel on each of the road systems of the State, originating in the respective governmental jurisdictions. This information, correlated with that obtained in the other studies, indicated the relation between the contributions to highways and the benefits obtained from the use of the highways. Most of the States made this study in the early period of the planning surveys and 23 of them have repeated it recently under somewhat modified procedures, known as the motor-vehicle-use study.

A fiscal study comprised an analysis of the financial reports for one year of the State and its various political subdivisions. This analysis indicated the source of all revenues and classified expenditures as to whether they were made for highways (or streets), education, public welfare and services, or for general government. The highway finance data are being kept current from year to year.

Another, called the road-cost (or road-life) study, involves research on highway investment, service lives and depreciation of various road types on the State highway system. Over the past 15 or 20 years, most States have built up a continuing record of the mileages constructed and retired. A number of States have also recorded their construction cost and analyzed salvage values, thus permitting determinations to be made of the highway investment in terms of grading, surfacing, and structures.

With the information thus obtained it is possible for highway departments to estimate the rate at which highways wear out and the cost of making needed replacements. Such information is extremely useful in scheduling long-range highway construction programs and in determining the rate at which highway needs will be met under various highway financing alternatives.

Urban Travel Studies

Another important group of studies included in the highway planning survey program are the urban area travel studies. These were not started until 1944, because it was not until the passage of the highway act of that year that appreciable Federal funds were made available for expenditure on Federal-aid projects in urban areas.

At that time, there was a lack of information on travel in urban areas which could be used as a basis for the planning of highway facilities that would best serve the public. In fact, no comprehensive survey methods had been developed which would give the needed information. Because of the complex nature of the city street network, and the shifting of travel from route to route, in search of the most favorable (or at least unfavorable), traffic volumes on existing streets are not a satisfactory guide to needed improvements. A study of origin and destination of trips, and the basic factors affecting travel was needed.

Before the passage of the 1944 Federal-aid Highway Act, in anticipation of its provisions with respect to urban funds, the Bureau of Public Roads developed a method for studying urban travel which would give the needed information. The method involved the interviewing of residents of a representative sample of dwelling units concerning the travel of the members of the household on a specified day and supplementing this with information obtained at roadside interviews on all important routes entering the city, so that the travel by nonresidents of the area could be included in the study. Information was obtained on origin and destination of trips, mode of travel, and trip purpose. Surveys based on these procedures have been or are being made in 115 urban areas and are being completely repeated in 6 of these to provide current data. In 167 additional urban areas, traffic surveys have been made that are somewhat less comprehensive in that they give information on automobile travel only.

These urban travel studies have been used in the planning of highway facilities, particularly expressway systems, and in determining the design features for these facilities. To be of maximum use for these purposes, the travel data must not only be brought up to date, but must be projected into the future. Much research is now being carried out by the Bureau and by others, to perfect the methods for doing this. The availability of electronic computers is making it possible to analyze large masses of data obtained in these surveys to establish relations between travel and land use and other factors so that future highway needs can be related to anticipated urban development.

Special Research Studies

In addition to the regular highway planning activities, there have been a number of special research studies, associated with planning, paid for in part

with highway planning survey funds and in part with other funds, including Bureau of Public Roads administrative funds. One group of these studies has to do with traffic operations, and deals with such subjects as driver behavior, highway accidents, and highway capacity. Another group consists of studies and tests relating axle-load frequencies to pavement damage and construction and maintenance costs.

Program Cost Breakdown

The relative amounts spent for the various phases of the highway planning survey have varied from year to year, but a breakdown of the program for the year 1955 is typical of recent years. This is approximately as follows:

	Percent	Percent
Traffic studies		
Traffic counting	20	
Urban origin and destination	16	
Weight studies	3	
Special traffic studies	7	
Subtotal		46
Inventory and mapping		22
Financial studies		
Finance and statistics	5	
Motor-vehicle use	2	
Highway cost and road life	4	
Subtotal		11
Special studies		18
Physical research		3
Total		100

State Uses of the Data

The States began putting the survey results to use as soon as they could be analyzed, in setting up road programs, determining priorities, designing individual projects, and in many other ways. The results have been used in reports to legislatures on many subjects such as the need for funds, the allocation of funds to different systems, the extent of the systems, size and weight limitations of vehicles, and road-user fees, especially license fees for trucks of different sizes.

Prior to the war, a number of the States prepared reports on highway needs, confined mainly to the State highway system. This was a good beginning, but it was not until after the war that really comprehensive highway-needs studies were made and reported. California was the first to issue a report covering the total needs of all systems, in compliance with a legislative request. The work was under the general guidance of the Automotive Safety Foundation. Extensive use was made of available highway planning survey data, supplemented with data from other sources, especially in cities. Over half of the States have now made comprehensive highway-needs studies of this character.

Federal Uses

The Bureau of Public Roads has correlated the data collected by the States and analyzed them to develop information of nationwide significance.

During the war, the planning survey data were of special importance in such matters as the allocation of strategic materials, gasoline rationing, and the relaxation of weight restrictions for trucks. Through a bridge record revised annually, the continuing needs of the armed services for information helpful in the routing of vehicles of unusual weights and dimensions are met.

Since the beginning of the war, traffic volume trends, vehicle miles of travel, ton-mileages hauled by trucks, and frequency of gross weights and axle loads of various magnitudes have been computed and published regularly. One of the important trends pointed out in these publications was the alarming increase in frequency of heavy axle loads that took place between 1936 and 1948. Partly as a result of these findings, stricter enforcement and other measures taken by the States and truck operators have resulted in reducing the frequency of heavy axle loads considerably below the 1948 peak. There has been a tendency during the last two years, however, for the frequency of heavy axle loads to increase again.

The survey information has been used by the Bureau in testimony before Congressional committees and in reports to Congress which have had an important effect on legislation. For example, the report "Toll Roads and Free Roads," submitted to Congress in 1939, showed the impracticability of a nationwide system of toll roads and laid the groundwork for consideration of an inter-regional system of free roads. Other reports to Congress, "Highways for the National Defense" (1941), and "Interregional Highways" (1944) resulted in the setting up of what is now known as the Interstate system. This 40,000-mile system (before the adding of 1,000 miles in the 1956 Act) constituted only about one percent of the road and street mileage but will, when completed, carry about 20 percent of the total traffic.

Other reports to Congress by the Bureau of Public Roads have had important effects on Federal legislation. Among these are "The Local Rural Road Problem" (1950), "Factual Discussion of Motor Truck Operation, Regulation and Taxation" (1951), "Progress and Feasibility of Toll Roads and their Relation to the Federal-aid Program" (1955), and "Needs of the Highway Systems" (1955). It was this latter report that laid the groundwork for the greatly expanded highway program provided for in the 1956 Federal-aid Highway Act. None of these reports could have been compiled without the benefit of the comprehensive data collected in the highway planning surveys.

Requirements of 1956 Act

The 1956 Act calls for five major studies and reports. These will require extensive analysis of planning survey data currently available and necessitate the collection of additional data of a type not previously obtained.

The first is the determination of the cost of completing the Interstate system in each State to standards adequate for anticipated 1975 traffic. This study assumes special importance because the results will be used as a basis for apportioning funds among the States.

The principal role of the highway planning divisions in this undertaking is the forecasting of 1975 design hourly volumes of traffic for each road section.

This involves a study of traffic diversion, generation and growth under anticipated conditions. These determinations are especially difficult because of the lack of experience with an extensive network of freeways, such as is proposed.

The second study is to determine the maximum desirable dimensions and weights of vehicles operated on the Federal-aid highway systems. The needed data are being obtained largely through a series of road tests and studies of vehicle operating costs carried out by the Highway Research Board in cooperation with the Bureau of Public Roads and other agencies. Also, a study is being made of road costs in relation to the actual frequency of weights on selected road sections, as a part of the highway planning survey operation.

The third study is to provide Congress with information that will aid it in making a determination with respect to reimbursement for highways on the Interstate system, both free and toll, that were constructed between 1947 and 1957 approximately to interstate standards.

The fourth study is to determine what steps can be taken by the Federal Government to promote highway safety. Federal assistance to State and local governments in the adoption of uniform highway safety and speed laws, the promotion of highway safety in the manufacture of vehicles, safety educational programs, and design and physical characteristics of highways are some of the subjects to be explored.

The fifth study is to aid Congress in determining what Federal taxes should be imposed to insure, insofar as practicable, an equitable distribution of tax burden among the various classes of persons using the Federal-aid highways or otherwise deriving benefits from them. It involves, among other things, the determination of the extent to which vehicles of different classes use the highways of the different systems, urban as well as rural, the loads which they impose and the cost of constructing and maintaining roads with design features adequate to accommodate these vehicles. It also involves a determination of operating savings because of superior design features, and an appraisal of indirect benefits. Much of the information needed in this study is not now available and must be obtained. For example, weight surveys have previously been confined to rural roads and do not provide information as to weight frequencies on city streets.

The completion of these studies will tax the ingenuities and resources of the highway planning survey personnel, at both the State and Federal levels. The results will undoubtedly greatly influence Federal legislation, and will be far-reaching, as regards the future of our highways.

Highway Planning Becomes Established

Twenty years ago the idea of highway planning drew mixed reactions. Prior to that time there had been limited activity that might be termed planning, but only then was the idea advanced of a comprehensive integrated effort to do a complete planning job. Some looked on the new idea with enthusiasm; others were mildly skeptical yet were willing to let it go along to see what developed; others looked on the idea with considerable doubt or trepidation; and still others with a certain disdain or amusement. Today highway planning is a solidly established function in all State highway departments. Perhaps the hopes of the more enthusiastic have not been fully realized, but the skeptics have generally been convinced, the fears of others that some ritual of planning might supersede sound judgment have proved

unfounded, and presently no one is amused. This change represents no insignificant accomplishment, for highway planning like many a new idea through history had to prove itself under trying and often pretty adverse conditions.

Yet, planning is still far from the goal originally set. Broadly speaking, the fundamental purpose of the activity was to place highway financing on a sound, continuing basis under which the cost of supporting the systems might be distributed as equitably as possible among the users and other beneficiaries and to provide facts on which the administrative and engineering officials might plan, construct, and operate the highway systems efficiently and in the best public interest. That this goal has not yet been reached is shown by the direction of the Congress in the 1956 Act to study the costs and benefits of the Federal-aid highway systems, and the actions now pending in many State legislatures looking toward additional needed highway revenues. In effect, highway planners are being directed by legislative bodies to accomplish what they have been trying for twenty years to do.

That the ultimate goal has not been reached is not necessarily grounds for criticism, although perhaps progress should have been greater than it seems to be.

Highway planning is now entering its third decade. Looking back it can be seen that the first half of the first decade was spent largely in the assembly of basic facts and laying the groundwork for keeping them up to date. Hardly had that first turning point been reached, however, when World War II engulfed all the Nation's efforts. While the war virtually put a stop to efforts to plan ahead it did serve to focus attention on the importance of what had already been accomplished. Many will recall the important uses made of traffic and other data already available or quickly supplied by the highway planning divisions during that period. They demonstrated the essentiality of highway projects so that the slim supplies of critical material that could be spared were made available to the highway departments. They aided in the routing of military convoys and war material shipments. They supported the need of gasoline and rubber to keep highway transportation alive. The war forced highway planning, like other highway functions, onto a hand-to-mouth basis. But the war also did this: it brought to the attention of highway administrators the idea that facts that would convince rationing officials could be equally useful in developing the continuing peace-time programs. The planning function became established.

Emphasis on Highway Needs

The second decade of highway planning began as the country was emerging from the war. Its highways had been regarded as expendable, and they were pretty well spent. With the resurgence of highway travel, and the inadequacies of the highways becoming increasingly evident, State after State undertook the highway-needs studies described earlier. During this decade greater attention was given to analysis and interpretation of the assembled facts and to their use in forecasting the highway needs of the future. And paralleling this activity as the decade wore on came the growing interest in financial surveys and the development of long-range financing programs to meet the anticipated needs. But with this shifting of emphasis, collection of

data was not forgotten. Great strides were made in improving methods and developing new techniques to improve the accuracy, extend the scope, and reduce the cost of the data needed for planning the expanding highway programs.

So now as highway planning enters its third decade it is solidly established under competent leadership in the States, adequately financed, yet handicapped as are all other highway functions by staffs of insufficient size. In this situation, what are the problems that must be faced?

First is the need of a current and more accurate appraisal of the highway needs. Three of the five studies called for by the 1956 Act require a State-by-State and system-by-system reappraisal of the status of the highways and of the cost of putting them into condition to accommodate present and future traffic. While this is a requirement of Federal legislation, it is no less a real need in most of the States. Although over half the States have made detailed needs studies since the end of World War II, many of these studies are now well out of date or are showing that estimates of future needs were based on unrealistic forecasts of traffic volume increases. The assembly of information in response to the direction of Congress to aid in future national policy decisions will absorb a major share of the efforts of the State highway planning divisions during the coming year or two, but the data so obtained will be of no less value to the States themselves in providing the basic facts on which State policies may be determined.

Much more must be done, however, to take full advantage of this reinventory of needs that will soon be available. Perhaps the most obvious thing is to develop a means of keeping the needs surveys current. It will be only four years until the estimate of the cost of completing the Interstate system must be revised, under the terms of the 1956 Act. The State legislatures should be equally interested in periodic appraisals of State highway needs. Should not right now the groundwork be laid for continuing needs inventories? As one administrator recently put it, "We went into a tail spin to get the data required by the 1954 Act. We had scarcely straightened out from that when we find ourselves in another to get the facts called for by the 1956 Act. Not that the facts aren't needed, but let's get organized so we don't go into tail spins every other year from now on."

Need for Studying Highway Benefits

Beyond this step several important areas on which attention should be focused come quickly to mind. First is the development of a much more accurate and refined method of determining the benefits resulting from the existence and use of the highway systems. With the increasing demands for funds for all governmental purposes in the years ahead means must be developed not only to estimate highway costs but also to appraise their benefits if the public is to be expected to support its highway systems in the degree that is justified. What actual savings in vehicle operating costs result from highway improvement? What is the actual value of time saved by passenger or commercial vehicles? What are the actual benefits to property newly served by new or improved highways? Wholly satisfying answers to these questions will be forthcoming only with far more comprehensive and precise data than are now available.

Long Range Programing Desirable

The second might be the development of practicable means of carrying the findings of the statewide and systemwide needs studies to the next logical step — the preparation of long-range construction programs that will give first priority to the projects that are, in fact, most urgent. Many devices have been employed, of which the sufficiency rating scheme is perhaps the most widely accepted. This device has advantages not possessed by other means but still is far from the scientific approach that should be possible of development with skill and imagination. The sufficiency rating has been likened to a sieve test for aggregates to be used in construction. It is a useful and essential test, but by no means an exclusive basis of decision. While projects in an annual program cannot be selected with the same objectivity as aggregates for paving mixtures, there is room and great need for the development of a sounder basis for orderly long-range programing.

Coordination with Planning Agencies

A third line of major effort is the coordination of highway planning with city and regional planning in and around urban areas. Highway construction under the interstate program alone within the years immediately ahead will have a profound effect on the growth and development of urban areas for many years to come. Properly located and designed the new planned access highways can stimulate desirable growth; improperly done, they can retard or even prevent the development best for the area. Little that will be done in public or private works will be of more permanent character than the highways that soon will be seen in every metropolitan area.

This problem of urban highway development is perhaps receiving more widespread attention than any other phase of the highway program. The National Committee on Urban Transportation, the joint committee of the American Municipal Association and the American Association of State Highway Officials, and the Committee on Urban Research of the Highway Research Board are actively attacking this problem from different directions. Research and planning must go hand in hand and both must be advanced with vigor if there is to be assurance the funds entrusted to the highway departments are to be wisely spent.

Perhaps never before have highway engineers been in position where correct decisions can accomplish so much good but where wrong decisions can be so costly. They should not be required to make such decisions alone, nor should they be faced with the necessity of projecting highways into an area unprepared with its own plans for the future. They should be supported and counseled by the city and regional authorities who should be ready with sound plans for over-all development, plans that have the assured support not only of all area officials, but of the public as well. Certainly, nothing that has been undertaken in highway planning demands more patient, skillful, objective analysis than the problem of coordination of planning in urban areas, nor does any effort promise more fruitful results. The tremendous population growth forecast for the two decades ahead will take place largely in the areas surrounding the present cities. They are areas of mutual interest to Federal, State, and local officials; they cannot be allowed to become

areas of disagreement. Fortunately, the work of highway planning and traffic researchers in the past few years has opened up the prospects of relating travel to land use, and as a consequence, of predetermination of highway needs in any area whose growth pattern can be forecast. Conversely, the growth pattern related to any proposed highway development can be equally well forecast. High-speed computers make relatively easy analyses that hitherto were virtually impossible, and once the basic facts of travel habits are recorded the desired answers can be turned out with great rapidity. The facts that can be produced in this area should provide grounds for the meeting of the minds of State and local planners and other officials as well as of the expressways their plans envision.

Other Areas to be Explored

There are many other areas in which effort will be expended in the decade ahead. More precise means of estimating future traffic growth and better coordination of the results of physical research with structural design to produce highways consistent with the traffic to come will be required. More uniformity in motor-vehicle registration practices and means of classifying vehicles in the registration records in a way consistent with their visual classification on the road are essential to studies of highway taxation. The road-life studies should be extended and expanded to include analyses of the life of the investment in the highway plant as well as its physical life expectancy. Improvement of the management of the highway departments and of the basic laws under which they operate are obviously needed and will be studied. Development and application of techniques to insure efficient operation of the costly high-volume expressways and finding the answers to the tragic loss of life and the staggering economic loss of traffic accidents are areas in which the need is great but in which insufficient progress has been made. Still others could be named now, and surely areas not now visible will become apparent in the years ahead.

Those who have been associated in one way or another with highway planning since its inception may well look back with pride on what are solid accomplishments and truly remarkable progress over a period of two decades. They may look ahead to a period in which on the one hand they must carry forward the planning activity now accepted as routine and on the other must explore and exploit uncharted areas to insure that the expansion in transportation that will inevitably continue may be orderly and beneficial. They can see the need to bring new skills and disciplines to bear on new problems as they become more complex and their solutions more difficult. They can see the need for wiser heads, stronger hands, and greater diligence, for those engaged in the highway planning effort.

But above all they can see ahead the prospects of more rewarding accomplishments. In the State highway departments the nation over may be seen highway planning with assured administrative support, with adequate financing, under competent and dedicated leadership, and supported by skilled staffs. Certainly there is every reason to look to the next decade with confidence. The need for sound work and the opportunity to perform it have never been greater.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1113 is identified as 1113 (HY6) which indicates that the paper is contained in the sixth issue of the Journal of the Hydraulics Division during 1956.

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JULY: 1019(ST4), 1020(ST4), 1021(ST4), 1022(ST4), 1023(ST4), 1024(ST4)[c], 1025(SM3), 1026 (SM3), 1027(SM3), 1028(SM3)[c], 1029(EM3), 1030(EM3), 1031(EM3), 1032(EM3), 1033(EM3)[c].

AUGUST: 1034(HY4), 1035(HY4), 1036(HY4), 1037(HY4), 1038(HY4), 1039(HY4), 1040(HY4), 1041(HY4)[c], 1042(PO4), 1043(PO4), 1044(PO4), 1045(PO4), 1046(PO4)[c], 1047(SA4), 1048 (SA4)[c], 1049(SA4), 1050(SA4), 1051(SA4), 1052(HY4), 1053(SA4).

SEPTEMBER: 1054(ST5), 1055(ST5), 1056(ST5), 1057(ST5), 1058(ST5), 1059(WW4), 1060(WW4), 1061(WW4), 1062(WW4), 1063(WW4), 1064(SU2), 1065(SU2), 1066(SU2)[c], 1067(ST5)[c], 1068 (WW4)[c], 1069(WW4).

OCTOBER: 1070(EM4), 1071(EM4), 1072(EM4), 1073(EM4), 1074(HW3), 1075(HW3), 1076(HW3), 1077(HY5), 1078(SA5), 1079(SM4), 1080(SM4), 1081(SM4), 1082(HY5), 1083(SA5), 1084(SA5), 1085(SA5), 1086(PO5), 1087(SA5), 1088(SA5), 1089(SA5), 1090(HW3), 1091(EM4)[c], 1092 (HY5)[c], 1093(HW3)[c], 1094(PO5)[c], 1095(SM4)[c].

NOVEMBER: 1096(ST6), 1097(ST6), 1098(ST6), 1099(ST6), 1100(ST6), 1101(ST6), 1102(IR3), 1103 (IR3), 1104(IR3), 1105(IR3), 1106(ST6), 1107(ST6), 1108(ST6), 1109(AT3), 1110(AT3)[c], 1111(IR3)[c]; 1112(ST6)[c].

DECEMBER: 1113(HY6), 1114(HY6), 1115(SA6), 1116(SA6), 1117(SU3), 1118(SU3), 1119(WW5), 1120(WW5), 1121(WW5), 1122(WW5), 1123(WW5), 1124(WW5)[c], 1125(BD1)[c], 1126(SA6), 1127 (SA6), 1128(WW5), 1129(SA6)[c], 1130(PO6)[c], 1131(HY6)[c], 1132(PO6), 1133(PO6), 1134(PO6), 1135(BD1).

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JANUARY: 1136(CP1), 1137(CP1), 1138(EM1), 1139(EM1), 1140(EM1), 1141(EM1), 1142(SM1), 1143(SM1), 1144(SM1), 1145(SM1), 1146(ST1), 1147(ST1), 1148(ST1), 1149(ST1), 1150(ST1), 1151(ST1), 1152(CP1)[c], 1153(HW1), 1154(EM1)[c], 1155(SM1)[c], 1156(ST1)[c], 1157(EM1), 1158 (EM1), 1159(SM1), 1160(SM1), 1161(SM1).

FEBRUARY: 1162(HY1), 1163(HY1), 1164(HY1), 1165(HY1), 1166(HY1), 1167(HY1), 1168(SA1), 1169(SA1), 1170(SA1), 1171(SA1), 1172(SA1), 1173(SA1), 1174(SA1), 1175(SA1), 1176(SA1), 1177(HY1)[c], 1178(SA1), 1179(SA1), 1180(SA1), 1181(SA1), 1182(PO1), 1183(PO1), 1184(PO1), 1185(PO1)[c].

MARCH: 1186(ST2), 1187(ST2), 1188(ST2), 1189(ST2), 1190(ST2), 1191(ST2), 1192(ST2)[c], 1193 (PL1), 1194(PL1), 1195(PL1).

APRIL: 1196(EM2), 1197(HY2), 1198(HY2), 1199(HY2), 1200(HY2), 1201(HY2), 1202(HY2), 1203 (SA2), 1204(SM2), 1205(SM2), 1206(SM2), 1207(SM2), 1208(WW1), 1209(WW1), 1210(WW1), 1211(WW1), 1212(EM2), 1213(EM2), 1214(EM2), 1215(PO2), 1216(PO2), 1217(PO2), 1218 (SA2), 1219(SA2), 1220(SA2), 1221(SA2), 1222(SA2), 1223(SA2), 1224(SA2), 1225(PO)[c], 1226 (WW1)[c], 1227(SA2)[c], 1228(SM2)[c], 1229(EM2)[c], 1230(HY2)[c].

MAY: 1231(ST3), 1232(ST3), 1233(ST3), 1234(ST3), 1235(IR1), 1236(IR1), 1237(WW2), 1238(WW2), 1239(WW2), 1240(WW2), 1241(WW2), 1242(WW2), 1243(WW2), 1244(HW2), 1245(HW2), 1246 (HW2), 1247(HW2), 1248(WW2), 1249(HW2), 1250(HW2), 1251(WW2), 1252(WW2), 1253(IR1), 1254(ST3), 1255(ST3), 1256(HW2), 1257(IR1)[c], 1258(HW2)[c], 1259(ST3)[c].

JUNE: 1260(HY3), 1261(HY3), 1262(HY3), 1263(HY3), 1264(HY3), 1265(HY3), 1266(HY3), 1267 (PO3), 1268(PO3), 1269(SA3), 1270(SA3), 1271(SA3), 1272(SA3), 1273(SA3), 1274(SA3), 1275 (SA3), 1276(SA3), 1277(HY3), 1278(HY3), 1279(PL2), 1280(PL2), 1281(PL2), 1282(SA3), 1283 (HY3)[c], 1284(PO3), 1285(PO3), 1286(PO3), 1287(PO3)[c], 1288(SA3)[c].

JULY: 1289(SM3), 1290(EM3), 1291(EM3), 1292(EM3), 1293(EM3), 1294(HW3), 1295(HW3), 1296(HW3), 1297(HW3), 1298(HW3), 1299(SM3), 1300(SM3), 1301(SM3), 1302(ST4), 1303 (ST4), 1304(ST4), 1305(SU1), 1306(SU1), 1307(SU1), 1308(ST4), 1309(SM3), 1310(SU1)[c], 1311(EM3)[c], 1312(ST4), 1313(ST4), 1314(ST4), 1315(ST4), 1316(ST4), 1317(ST4), 1318 (ST4), 1319(SM3)[c], 1320(ST4), 1321(ST4), 1322(EM3), 1323(AT1), 1324(AT1), 1325(AT1), 1326(AT1), 1327(AT1), 1328(AT1)[c], 1329(ST4)[c].

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c. Discussion of several papers, grouped by Divisions.

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